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# ALCOHOL FUELS AND LEAD PHASEDOWN

## A REPORT

PREPARED BY THE

CONGRESSIONAL RESEARCH SERVICE

FOR THE USE OF THE

SUBCOMMITTEE ON FOSSIL AND SYNTHETIC FUELS

OF THE

COMMITTEE ON ENERGY AND COMMERCE  
U.S. HOUSE OF REPRESENTATIVES



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 COMMITTEE ON ENERGY AND COMMERCE  
 WASHINGTON, DC 20515

July 25, 1986

The Honorable John D. Dingell  
 Chairman  
 Committee on Energy and Commerce  
 U.S. House of Representatives  
 Washington, DC 20515

Dear Mr. Chairman:

The enclosed report entitled "Alcohol Fuels and Lead Phasedown," was prepared by the Congressional Research Service for the Subcommittee on Fossil and Synthetic Fuels. The report examines the effect of the current lead phasedown levels on the domestic refining industry as well as the possibility of a future total lead ban.

The report also looks at the potential and problems of alcohol fuels as a substitute for lead and summarizes existing legislation related to alcohol fuels.

I believe that this report merits the attention of Members concerned with the future quality, quantity, and source of the nation's gasoline supplies. I request that it be published as a Committee Print.

Sincerely,

*Philip H. Sharp*  
 Philip H. Sharp  
 Chairman

PRS:rs

Enclosure

III  
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#### ABSTRACT

The Environmental Protection Agency (EPA), reacting to concerns over the health effects of lead in the environment, issued regulations sharply restricting the allowable lead content of gasoline. Petroleum refiners therefore need to make up for the loss of octane boosting qualities formerly provided by lead. The refiners can increase octane by modifying refining processes, or they can use oxygenates, among which are the alcohol fuels. Sales of alcohol (ethanol and methanol) for fuel use have climbed to nearly a billion gallons per year, and could climb much higher if alcohol were used as an octane booster. However, uncertainties about alcohol fuel supplies, fed by intra-industry conflicts, could influence petroleum refiners against the alcohol fuels option.

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## SUMMARY

1. THE LEAD PHASEDOWN

Lead has been used extensively as an additive in gasoline to prevent premature detonation in automotive engine cylinders, commonly known as "knocking" or "pinging". This phenomenon reduces engine efficiency and can cause engine damage. The ability of a fuel to resist premature detonation is measured by an "octane rating". Since lead increases that rating, lead used for this purpose is called an "octane booster". Lead in automotive fuels is in the form of a chemical compound called tetraethyl lead (TEL). No other compounds have been found that even come close to approaching the effectiveness of lead alkyls on a gram for gram basis in boosting octane.

Lead has been known to be a health hazard for many years. While the principal source of environmental lead has been lead-based paint, lead in gasoline has been increasingly recognized as a harmful environmental contaminant. In 1971, therefore, the Environmental Protection Agency (EPA) began regulatory proceedings intended to reduce ("phasedown") lead in gasoline.

These proceedings proved difficult and contentious, as the phasedown was challenged by petroleum refiners and TEL manufacturers. EPA's authority to enforce phasedown regulations was upheld by the Supreme Court in 1976, at which time lead in gasoline averaged 1.6 grams per gallon (g/gal). EPA then issued a schedule providing for phasedown to proceed gradually, to an industrywide

level of 0.5 g/gal by 1979. An interim standard of 0.8 g/gal went into effect in 1978 with some exceptions, but the oil crisis following the Iranian revolution in 1978-79 caused further action to be deferred.

With the Reagan Administration's strong commitment to deregulation, there were expectations in 1981 that the lead phasedown might be delayed, modified, or even rescinded. The argument was made that the gradual turnover of the automotive fleet to catalyst-equipped cars, designed to operate on unleaded gasoline, would achieve the desired reductions in lead emissions without the need for governmental action. However, in the face of continued uncertainty about the effect of observed blood lead levels, EPA decided in 1982 to retain the lead phasedown regulations, abandoning the "pool average," which by then had reached 0.5 g/gal, and instead established a standard of 1.1 g/gal for leaded gasoline only. In 1984, the agency invited comment on a further strengthening of the standard when it was observed that demand for leaded gasoline was not falling as rapidly as had been forecast, and new health studies indicated that the health effects from lead in the bloodstream were more serious than had been estimated previously.

In March 1985, EPA issued a final rule establishing an interim standard for leaded gasoline of 0.5 g/gal on July 1, 1985, dropping to 0.1 g/gal as of January 1, 1986. As late as spring 1986, the reduction to 0.1 g/gal had not had any apparent negative consequences on gasoline supply nor was it adding significantly to problems that had been facing the refining industry. Because many refiners are drawing upon "lead credits" earned by previously producing leaded gasoline with less lead content than the ceiling allowed by the regulations, it has been predicted that the lead pool in 1986 will probably average

closer to 0.3-0.5 g/gal, declining to 0.1 g/gal by the end of 1987 when the lead credits expire.

It is possible that lead may be eliminated altogether at a later date, but EPA has indicated that it will not issue such a rule until it has established what fraction of the older and heavy-duty vehicle population might be at risk operating on lead-free gasoline, or until after-market products are available which would protect such vehicles from any possible damage.

## 2. THE ALCOHOL FUELS OPTION

In response to the lead phasedown, petroleum refiners are reviewing possible options for increasing the octane rating of their gasoline by enough to replace the lead being removed. Among these possible options are the alcohol fuels, methanol and ethanol. In recent years, a domestic alcohol fuels industry has come into existence, based upon the distillation of ethanol from corn. U.S. fuel ethanol production in 1985 was estimated at 650 million gallons, enough to produce 6.50 billion gallons of the ten percent "gasohol" blend. Ethanol imports from Brazil and methanol from the petrochemical industry are also becoming significant contributors to the automotive fuels pool, with estimated sales for 1985 of 130 million gallons for Brazilian ethanol and 265 million gallons for methanol in all its forms. Methanol is used most often in formulating mixtures and compounds such as oxinol and MTBE (discussed below). Thus total sales of alcohol for fuel use in the United States have now reached over a billion gallons per year, or about 1 percent of the total automotive fuel consumed. When used in approved quantities, i.e., in blends of up to ten

percent for ethanol or up to five percent for methanol, the alcohol fuels are compatible with existing automotive engines, and they do supply the octane-boosting properties necessary for replacing the lead being removed from gasoline.

However, the alcohol fuels option is not without risk for the refiners. Domestic ethanol production is dependent upon the U.S. corn crop for supply and is heavily subsidized by exemptions from Federal and State gasoline excise taxes. Imported ethanol has been under fire from the domestic producers who see it as unfair competition, and methanol use is restricted by the Federal EPA because of vapor pressure considerations. Given these factors, and also given the risk associated with any agricultural crop which is subject to the vagaries of weather, a refiner might well prefer to employ one of the other octane-boosting options open to him. In addition, the complex process economics of petroleum refining may well make other options cheaper for some refiners, even with the subsidies given to alcohol fuels.

### 3. CONSIDERATIONS FOR THE PETROLEUM REFINER

The octane-boosting options that refiners have generally been most comfortable with are process options. Process options include a range of normal refining processes that yield higher octane-blending streams and modifications of those processes to increase octane value. Modifications can include installing improved catalysts and operating under more severe conditions of temperature and pressure. In addition to modifying existing units, refiners are also constructing new octane-boosting capacity.

Among the process options available to refiners, isomerization <sup>1/</sup> is one of the most attractive. Isomerization units currently provide about one percent of the total gasoline pool, but this contribution is expected to increase considerably as several projects under construction come on stream. Total (recycle) isomerization yields a blending stream with an antiknock index of 88 and, at the same time, provides a higher octane use for light straight-run (LSR) naphtha. The latter consideration is important since LSR naphtha and natural gasolines constitute the major low octane component of the gasoline pool.

Aromatics are a class of hydrocarbons that have a high octane value. Aromatics are produced in several refining processes but the two major processes that together produce about 90 percent of the aromatics in gasoline are the reforming units and fluid catalytic cracking (FCC) units. Reformate contains 35 to 60 percent aromatics and FCC gasoline ranges from 15 to 35 percent aromatics. Both of these processes are major candidates for modification and increased use. Reformate and FCC gasoline currently contribute about 70 percent of the gasoline pool. Consequently, raising the blending octane value (BOV) of the output streams from these units by only one or two octane numbers can have a significant effect on the octane value of the total pool. In this regard, however, some concerns have been raised about the health effects of increased use of aromatics in gasoline. Most of this concern has focused on benzene, which is a known carcinogen. What effect increased benzene in gasoline may have on health is largely unknown and extremely difficult to quantify. Benzene, fortunately, is one of the lesser aromatic components of gasoline. Gasoline currently averages about 1.2 percent benzene, and about 27 percent aromatics.

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<sup>1/</sup> The isomerization process converts normal (straight-chain) paraffins into their isomers (branched chains) by using heat and catalysts.

Another process option that produces a high octane product is alkylation. <sup>2/</sup> Alkylation currently contributes about 11 percent of the total gasoline pool and several refineries have alkylation projects under construction. Other octane enhancing options include polymerization and the Dimersol process. <sup>3/</sup>

The use of oxygenates, among which are the alcohol fuels, is another option for the refiner. The only oxygenate currently made and blended into gasoline inside the refinery is methyl tertiary butyl ether (MTBE). The use of MTBE as a blending component is expected to increase significantly since it has a high blending octane value of 110. MTBE is made from methanol and offers a way to use methanol indirectly in motor fuel without problems which are associated with it as a blending component.

Because of their affinity for water, alcohols are not generally accepted for pipeline transport, and, thus, are not generally blended in a refinery. Pipelines will, however, accept suboctane gasoline for transport, which allows alcohols to be used as blendstock in their market area. From the refiner's point of view, this provides an option for marketing suboctane gasoline. While the refiner would get fewer dollars per barrel for suboctane gasoline, he benefits from not having to incur the expense of upgrading processing or purchasing higher octane components. The extent to which refiners will exercise this option will depend on the attractiveness of the economics to the individual refinery. The economics of octane enhancement depend on many

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<sup>2/</sup> Alkylation is a polymerization process uniting olefins (hydrocarbon chains with at least one double bond) and isoparaffins (usually isobutane) using sulfuric acid or hydrofluoric acid as a catalyst.

<sup>3/</sup> In a refinery polymerization is a process for combining two or more olefins (usually propylenes and butylenes) to form a molecule of higher molecular weight using phosphoric acid as a catalyst. The Dimersol process catalytically converts propylene to its dimer, isohexane.

variables, most of which are site specific. Some of these variables include the following:

- o The quality of crude petroleum processed;
- o The market opportunities for the refiner's complete slate of products;
- o The response of the individual refinery's gasoline pool to a particular octane enhancer;
- o The cost or benefit of vapor pressure adjustment that an octane enhancer may require;
- o The local availability of octane enhancers, including the costs of delivery versus the costs of onsite production. For alcohols, the costs might include modifying distribution and storage systems to remove water;
- o Value to the refiner of public acceptance of oxygenates vis-a-vis auto maker's recommendations, etc; and
- o State and Federal tax considerations, particularly for alcohol fuels.

At this time it is impossible to predict how all these variables will sort out and what percentage of refiners will use alcohol fuels as an octane booster.

#### 4. THE ALCOHOL FUELS INDUSTRY AND THE LEAD PHASEDOWN

Sales of alcohol for fuel use in the United States have climbed from virtually zero to nearly a billion gallons per year in under a decade, with gasoline replacement being the primary purpose for the alcohol, not octane enhancement. The octane boosting characteristics of methanol and ethanol are well established, and Federal and State exemptions from highway taxes improve the economic picture for alcohol blends. Our calculations (see p. 97-101) indicate that if blending with alcohol is the primary method used to replace lead as an octane booster, the potential market for alcohol fuels could theoretically

reach ten billion gallons per year, assuming that the Federal tax exemption remained in place. Thus it would appear that the alcohol fuels industry is well situated to benefit by providing octane boosting properties to the auto fuel market as lead is phased down. And yet a prudent petroleum refiner, considering the costs, benefits, and potential risks to his firm of choosing to go with alcohol fuels instead of making the refinery modifications open to him, could see factors weighing against the alcohol fuels option.

The domestic ethanol industry, which is now the principal source of fuel alcohol, uses the Midwestern corn crop as its supply source. It therefore is dependent on the well-known uncertainties associated with agriculture. Weather-related disasters such as drought, flood, hail, excessive heat, or early frost can destroy large portions of the crop. These conditions, as well as abrupt changes in international markets caused by famines, wars, or crop failures elsewhere in the world, could cause supply shortages and/or price rises that would leave a refiner who had chosen the alcohol option in a difficult situation.

The advantages to the alcohol fuels industry from the Federal and State highway tax exemptions might also be seen by the refiner as a double-edged sword. What the Congress and the State legislatures gave they could also take away. The Federal tax break expires in 1992, and there have been efforts to end it at an earlier date. Some of the State tax advantages, such as California's, have already been repealed. On both Federal and State levels, factors working against continued tax advantages for the alcohol fuels include the growing concern by highway builders and users over the depletion of their funds caused by these tax provisions, which divert revenue from the Federal Highway Trust Fund and similar State funds, as well as the tight budget climate which works against continued tax preferences of any kind.

In addition, at least in the short run, the oil price drop now under way works against the choice of alcohol fuel, by making the alcohol fuels less economically attractive compared to petroleum products. Alcohol fuel advocates believe that once alcohol is accepted as an octane enhancer, it will be priced in competition with other octane boosting methods and therefore will not be as vulnerable to oil price fluctuations.

With regard to ethanol imports, two more factors would be added to the above uncertainties. International relations are notoriously changeable, and a U.S. refiner looking into the future could not find any guarantee that ten or twenty years from now Brazil would be willing to sell ethanol to the United States, or that other nations would step in if Brazil turned away. After the problems OPEC caused the United States and other oil importing nations, it could be imprudent for this country to become overly dependent again on an imported fuel.

A more immediate threat to ethanol imports, however, derives from the efforts by the domestic ethanol industry to keep them out. Through legal actions and by lobbying the Congress, domestic fuel alcohol producers have been virtually waging war on ethanol imports from Brazil and the Caribbean nations. The importers for their part have been resourceful in finding new loopholes and pathways through the import barriers as other paths are closed. Again, a prudent petroleum refiner viewing this intrasectoral warfare within the alcohol fuels industry might choose to stay away from the battle, by opting for other octane boosting methods, instead of attempting to forecast the outcome of the "alcohol war."

With regard to methanol, its low cost and potential availability from coal, wood, or solid wastes makes it an attractive energy option for the

future. However, its present usefulness is limited by its limited compatibility with existing automobile engines and by Federal environmental restrictions. The "Du Pont" blend of 5 percent methanol and 2.5 percent ethanol might help meet these concerns, since this blend could combine the automotive compatibility of ethanol with methanol's low cost. However, an EPA ruling in January 1985, while theoretically allowing the use of the blend, in practice has virtually excluded its use by including restrictions on allowable vapor pressure which it cannot meet. Again, a prudent oil refiner with an immediate octane boosting decision to make might view reliance on methanol as too risky.

Despite the uncertainties, the alcohol fuels industry might be in a situation where the whole is greater than the sum of the parts. While any one of the three alcohol fuel options--domestic ethanol, imported ethanol, and methanol--might be seen by refiners as limited and unreliable, availability of all three options might reassure refiners that alcohol fuels would provide the necessary stability and continuity of supply. For instance, a temporary shortfall in U.S.-grown corn for the manufacture of domestic ethanol could be handled by obtaining imported ethanol or Du Pont-blend methanol until the corn supply returned to normal. Having the advantage of multiple alcohol fuel choices would make alcohol fuel in general more attractive to a petroleum refiner.

A regional approach, which is suggested by the alcohol fuels market structure, might help minimize conflict among alcohol fuel suppliers. Domestic ethanol could continue to be the preferred alcohol fuel in the Midwestern States, where local supply and State tax breaks have helped it become well established. Imported ethanol from Brazil and the Caribbean can easily reach the major Sun Belt States, such as Florida, Texas, and California, where

ethanol has had some success. Methanol, as part of the Du Pont blend, might be successful in the Northeastern States, which thus far have largely been resistant to alcohol fuels.

Thus the lead phasedown and the resulting need for other sources of octane boosting could provide a major stimulus to all portions of the alcohol fuels industry, provided that the industry takes steps to reduce intra-industry conflicts and capitalize on this opportunity. On the other hand, low cost petroleum and political uncertainties affecting alcohol fuel costs could bode ill for the industry in the short-term.

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INTRODUCTION

Health hazards associated with lead in the environment have caused the Environmental Protection Agency, after long consideration, to issue regulations sharply limiting the use of lead as an automotive fuel additive. The phaseout of lead has forced the petroleum refining industry to search for alternatives to lead as an octane booster. The alcohol fuels, methanol and ethanol, are among the possible alternatives. An alcohol fuels industry, based on the distillation of ethanol from corn, has developed in the United States over the past decade. Sales of domestic ethanol for fuel use in 1985 were estimated at 650 million gallons, enough to produce 6.50 billion gallons of the 10 percent "gasohol" blend. Ethanol imports from Brazil and methanol from the petrochemical industry are also becoming significant contributors to the automotive fuels pool; sales of imported ethanol for fuel in 1985 were estimated at 130 million gallons, and sales of methanol for fuel at 265 million gallons.

This paper discusses the lead phasedown, the resulting "octane gap," and the contribution that alcohol fuels might make toward filling that gap. Chapter I, "History of the Lead Phasedown," was written by Robert L. Bamberger, a specialist in energy policy with the Environment and Natural Resources Policy Division of the Congressional Research Service (CRS). Chapter II, "The Impact of Lead Phasedown on the Refining Industry," was written by James E. Mielke, a specialist in science and technology with the Science Policy Research Division of CRS. Chapter III, "Alcohol Fuels--Background and Current Status," is by

Migdon Segal, an analyst in energy technology with the Science Policy Research Division. Mr. Segal also wrote the introduction and conclusions and coordinated the projects.

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## I. HISTORY OF THE LEAD PHASEDOWN

A. INTRODUCTION AND OVERVIEW

"Lead phasedown" refers to a regulatory schedule, developed in the mid-1970s in response to the contribution of gasoline emissions to observed levels of atmospheric lead. The Clean Air Act confers authority to "control or prohibit the manufacture . . . or sale" of fuels or fuel additives whose emissions are "reasonably anticipated to endanger the public health or welfare," or which are believed to impair devices, such as the catalytic converter, designed to control those emissions. <sup>1/</sup>

The use of lead in gasoline increases the resistance of gasoline to premature detonation in engine cylinders. Preignition or premature detonation of gasoline--which is recognized as engine "knocking" or "pinging"--reduces engine efficiency and can, if a chronic problem, cause engine damage. Its causes can be lean air/fuel mixtures which cause uneven distribution of gasoline in the engine cylinder, overadvance of ignition timing, and the buildup of carbon deposits in the combustion chamber. The octane rating of a fuel is a measurement of its ability to withstand preignition or detonation. Tetraethyl lead (TEL) was the principal and most widely applied additive developed to reduce the volatility of gasoline.

---

\*By Robert L. Bamberger, Specialist in Energy Policy, Environment and Natural Resources Policy Division.

<sup>1/</sup> See Section 211(c)(1), 42 U.S.C. 7545(c)(1).

The toxicity of lead has been recognized for many years; but there has been considerably less agreement about what is an acceptable incidence of measured lead in the human bloodstream, and what sources of lead in the environment should be actively regulated.

In late January 1971, the Environmental Protection Agency declared its intent to institute a gradual phasedown of lead in gasoline. Opposition to the regulations was strong, largely because the economics of boosting octane with lead substitutes or more capital-intensive refining processes were seen to be unnecessary. It stood to reason that the introduction of catalytic converters in automobiles and the requisite use of unleaded gasoline, would achieve a phased reduction in atmospheric lead as the automotive fleet turned over, with cars that burned leaded fuel replaced by those requiring unleaded. Partly at issue was whether this "natural" phasedown would occur at a pace commensurate with perceptions of the risks to the public from leaded fuel.

It is generally agreed that the principal source of lead in the total environment has been lead-based paint--though food, water, dust and air have been identified as additional sources of lead. While airborne lead does not represent a significant percentage of lead found in the environment, gasoline itself is certainly a major source of airborne lead. But there has been considerable disagreement within the scientific community about the degree of causality between observed gasoline lead and blood lead levels. During the course of the phasedown's checkered history, perceptions have changed as to whether, and how intensely regular gasoline--as an incremental source of environmental

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lead--should be regulated. 2/ In the absence of a demonstration of causality--beyond challenge--linking gasoline to observed levels of blood lead, some would be disinclined to regulate. Others might argue that even a suspicion of causality in matters of human health should prompt regulatory activity as a measure of safety against the time when more information is reliably known.

The pace of the lead phasedown since it was first proposed, and the character of the debate over the program, have turned on such issues and value systems as these, and are detailed in the history which follows.

#### B. EARLY HISTORY OF THE LEAD PHASEDOWN: DEFERRALS AND MORE DEFERRALS (1971-1980)

Though the phasedown regulations were issued initially in 1971, it was not until December 1973 that a final rule was issued, calling for a reduction to 0.5 grams per gallon (gpg) by January 1, 1979. 3/ The regulations were challenged in court by refiners and lead additive manufacturers, and EPA did not enforce the phasedown while the litigation was pending. EPA's authority to enforce the regulations was confirmed in a decision by a U.S. court of appeals in March 1976. The Supreme Court declined to intervene.

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2/ The results of a number of studies are reviewed and critiqued by witnesses on both sides of the issue in these lively hearings: U.S. Congress. Senate. Committee on Environment and Public Works. Airborne Lead Reduction Act of 1984. June 22, 1984. S. Hrg. 98-978. See, in particular, the testimony of Dr. Jerome F. Cole, President, International Lead Zinc Research Organization, Inc., p. 103-110.

3/ The 0.5 gpg standard was initially a "pool average" standard calculated by dividing total grams of lead used in the production process by the total gallons of all types of gasoline produced.

Lead in gasoline averaged 1.6 gpg in mid-1976. The schedule initially called for a phasedown to 1.4 gpg beginning October 1976, declining to 1.0 gpg in January 1977, 0.8 gpg by January 1, 1978, and 0.5 gpg beginning January 1, 1979. <sup>4/</sup>

When it became apparent that it would be difficult for the industry to reduce lead content without a deleterious effect on short-term gasoline supply, the standard was revised in late September 1976. The interim standards for 1976 and 1977 were dropped and the 0.5 gpg standard was postponed to October 1, 1979. Additionally, the interim 0.8 gpg standard was suspendable for individual refiners demonstrating that compliance with the 0.8 gpg standard was infeasible without volumetric cutbacks in gasoline production. However, refiners could not be excused from complying with the 0.5 gpg standard by October 1979.

Small refiners persisted in arguing that the phasedown regulations particularly disadvantaged their operations, and additional exemptions were granted them in 1978. When supplies proved plentiful as the summer driving season approached, EPA was reportedly considering stiffening the requirements on small refiners. But it was argued that the industry had scheduled its capital investment and improvement decisions upon anticipation of the October 1979 deadline, and that it would not be productive to accelerate the schedule at this point.

It was just as well that EPA did not revise the schedule again in mid-1978, because the disruption in oil supplies following the overthrow of the Shah of Iran in late 1978 resulted in a further deferral of the lead phasedown schedule. Although Iran resumed exports in March 1979 at roughly 60 percent

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<sup>4/</sup> Useful summations of the history of the lead phasedown are: U.S. Dept. of Energy. Assistant Secretary for Environment, Safety and Health. Office of Environmental Analysis. Gasoline Octane Enhancement: Technology, Economics, and Environmental, Health and Safety Considerations. July 1985. DOE/PE/72013-1. p. II-1-II-9. See also: U.S. Library of Congress. Issue Brief ME83220: Gasoline: Lead Phasedown.

of levels prior to the overthrow of the Shah, other producers seemed disinclined to permanently offset what appeared to be an indefinite reduction in world oil supply. Unsure of their ability to secure adequate supplies of crude, the major companies began to impose allocations on gasoline deliveries to retail outlets. Severe shortages of unleaded made policymakers conscious of the gasoline production penalty associated with the phasedown, estimated at that time between 350,000-450,000 barrels per day. The shortages also raised the specter that motorists might misfuel catalyst-equipped cars with leaded gasoline, rendering the catalyst ineffective in controlling vehicle emissions. <sup>5/</sup>

In April 1979, President Carter directed EPA to defer the 0.5 gpg standard to October 1, 1980, and maintain 0.8 gpg as the interim standard provided that refiners agreed to produce additional quantities of unleaded gasoline. The unleaded production requirements were subsequently suspended when they had the unanticipated effect of over-supplying unleaded gasoline to the market.

#### C. REAPPRAISAL OF THE STANDARDS: THE REAGAN YEARS (1981-85)

In January 1980, E. I. Du Pont filed a petition requesting repeal altogether of the lead phasedown regulations. Du Pont argued that the turnover of the fleet was achieving the desired reductions and that the potential crude oil savings from repeal considerably outweighed the marginal benefits to air quality which the phasedown would achieve in the interim. EPA denied the petition in August

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<sup>5/</sup> EPA has estimated that engine misfueling can increase emissions of conventional pollutants by a factor of eight. See: U.S. Environmental Protection Agency. Office of Policy Analysis. Costs and Benefits of Reducing Lead in Gasoline. Mar. 26, 1984. p. IV.2.

1980, arguing that "the intervening . . . years could be critical for the millions whose health could be affected adversely." 6/

Shortly thereafter, the new Reagan Administration declared its intention to eliminate "excessive" Federal regulation, and to avoid imposing future regulations whose benefits will not demonstrably exceed their costs. 7/ To further these objectives, President Reagan established a Task Force on Regulatory Relief led by Vice President Bush. In August 1981, the Vice President announced that the Administration would reconsider the lead phasedown rules, taking into account the associated energy penalties and capital requirements with compliance.

On February 22, 1982, EPA issued two notices of proposed rulemaking. Citing the anticipated decline in leaded gasoline sales, EPA solicited comments on whether (1) relaxation or rescission of the 0.5 gpg standard was warranted, and whether (2) small refiners should be subject to different standards. Options identified by EPA included outright rescission, raising the standards to 0.65, 0.8 or 1.0 gpg, retaining the 0.5 gpg standard for urban areas, or not altering it at all. Until the first of these issues was resolved, EPA suspended the deadline for compliance by small refiners with the 0.5 gpg standard. 8/

Gasoline blenders, who purchased unmarketable low-octane fuel and blended it with lead, were also an issue. Because the blenders did not refine crude, they were not subject to the phasedown regulations, and were able to sell leaded

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6/ See: 45 FR 54092-3. DuPont subsequently filed a petition to postpone the 0.5 gpg standard to Oct. 1, 1981.

7/ The Administration commented, "Some regulatory activity is needed to protect the health and safety of the public. However, it does not follow that all health and safety regulation is necessary . . . or that all such regulation even improves health and safety." See: U.S. Dept. of Energy. Securing America's Energy Future: The National Energy Policy Plan: July 1981: p. 15.

8/ Federal Register, v. 47, no. 35, Feb. 22, 1982. p. 7812 et seq.

fuel more cheaply. Hearings held by EPA reflected some division within the refining industry. Witnesses from trade associations representing the larger, integrated refiners--who had earlier urged a rescission of the standards--now argued only for a relaxation of the standards. It appeared that the large integrated refiners, having made some investment in capital equipment to meet the standards, preferred to accommodate some standard in return for provisions that would thwart gasoline blenders by holding them to some standard as well. Small and independent refiner associations continued to maintain the position that there was no longer justification for regulating leaded fuel.

In August 1982, EPA announced that it would retain the 0.5 gpg standard. The agency proposed to abandon the "pool average" standard in favor of a system based strictly on leaded fuel. <sup>9/</sup> The final rule, announced in October 1982, established a standard for leaded gasoline of 1.10 gpg. Small refiners were allowed an interim standard of 1.9 gpg until July 1, 1983; thereafter they, too, were to meet the 1.1 gpg standard. EPA argued that it was "reasoned judgment" that lead from gasoline was still "a significant source of lead in dust and dirt as well as airborne lead," and that it was "reasonable to reduce preventable sources of lead exposure including . . . gasoline." <sup>10/</sup>

The regulations continued to be challenged in court by various small-refiner groups, and in January 1983, the interim standards were eased for small

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<sup>9/</sup> One reason for abandoning the "pool average" standard was that refiners with greater unleaded production could add more lead to their leaded production without violating the standard. As unleaded gasoline demand and production increased, greater amounts of lead could be added to the leaded production. Depending upon the yield of leaded to unleaded gasoline produced in certain regions, the average lead content of gasoline might differ widely in certain urban areas, a trend already confirmed at the time by agency measurements.

<sup>10/</sup> U.S. Federal Register, v. 47, no. 167, Aug. 27, 1982. p. 38070 et seq.

refiners to 2.65 or 2.15 gpg, depending upon the refinery's volume. A subsequent court decision, issued in April, affirmed the rationale for the regulations. In Small Refiner Lead Phase-Down Task Force v. EPA, the court noted that:

In summary, the demonstrated connection between gasoline lead and blood lead, the demonstrated health effects from levels of 30 ug/dl [micrograms per deciliter] or above, and the significant risk of adverse health effects from blood lead levels as low as 10-15 ug/dl would justify EPA in banning lead from gasoline entirely. 11/

Preoccupation with lead levels became a front-line issue again during 1984. Even after allowing for periods of depressed automobile sales, demand for leaded gasoline was not falling as rapidly as was forecast. EPA surveys suggested that 13 percent of all catalyst-equipped cars were being misfueled with leaded gasoline, presumably because consumers either wanted to save money or to obtain higher octane. New scientific studies, cited by the court decision noted earlier, were also indicating increased instances of anemia, behavioral and cognitive effects from blood lead levels once thought tolerable.

The announcement that the Task Force on Regulatory Review was to review the lead phasedown had triggered some expectations that the Reagan Administration, consistent with its pledge to discourage excessive regulation, would abandon or relax the lead phasedown. Instead, the new research on blood lead levels played a major part in EPA's reaffirmation of the lead standards, supported by an internal EPA study which concluded that there would be significant benefits from further reductions in lead, or a ban on it altogether. The EPA study examined two options, either to: (1) ban all production of leaded gasoline; or to (2) further reduce the allowable lead content of gasoline from 1.1 gpg

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11/ Small Refiner Lead Phase-Down Task Force v. EPA, 705 F.2d 506 (D.C. Cir. 1983), 705 F.2d at 531.

to 0.1 gpg. <sup>12/</sup> For both options, EPA concluded that the monetized benefits (estimated for calendar year 1988) of either reducing or eliminating lead in gasoline would significantly exceed the costs.

A summary of EPA's estimates of costs and benefits for each option is shown below. The two essential categories of benefits are those stemming from a further reduction in lead emissions and a reduction in emissions of conventional pollutants which would continue to increase if engine misfueling continued. The benefits also include savings in vehicle maintenance, reduced public health costs, and savings in damage to materials and the environment. <sup>13/</sup>

In the summer of 1984, EPA proposed a reduction in lead content to 0.1 gpg in 1986, and invited comment on how and when a total ban on leaded gasoline might be instituted. <sup>14/</sup> In early March 1985, a final rule was announced, establishing a lead standard of 0.5 grams per gallon of leaded fuel, decreasing to 0.1 gpg on January 1, 1986. EPA is also weighing a number of alternatives for the elimination of lead altogether, including a ban as early as January 1, 1988. <sup>15/</sup>

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<sup>12/</sup> See: U.S. Environmental Protection Agency. Office of Policy Analysis. Costs and Benefits of Reducing Lead in Gasoline. Draft Final Report. Mar. 26, 1984.

<sup>13/</sup> Costs and Benefits of Reducing Lead in Gasoline, op. cit., p. i-iv.

<sup>14/</sup> See: Federal Register, v. 49, no. 150, p. 31031 et seq. [Aug. 2, 1984].

<sup>15/</sup> See: Federal Register, v. 50, no. 45, p. 9386 et seq.

SUMMARY TABLE 1. Comparison of Benefits and Costs of Lead Reduction Options in 1988 (millions of 1983 dollars)

|                                                      | Low-lead Option*                       | All Unleaded**                          |
|------------------------------------------------------|----------------------------------------|-----------------------------------------|
| <u>COSTS</u>                                         |                                        |                                         |
| Manufacturing Costs                                  | \$503                                  | \$691                                   |
| Non-monetized Valve Damage to Engines that Need Lead | --                                     | D                                       |
| TOTAL COSTS                                          | \$503                                  | \$691+D                                 |
| <u>BENEFITS</u>                                      |                                        |                                         |
| Maintenance Benefits                                 | \$660                                  | \$755                                   |
| Environmental and Health Benefits                    |                                        |                                         |
| <u>Conventional pollutants</u>                       |                                        |                                         |
| Reduced damage by eliminating misfueling             | \$404                                  | \$404                                   |
| Non-monetized health benefits†                       | H <sub>1</sub>                         | H <sub>1</sub>                          |
| <u>Lead</u>                                          |                                        |                                         |
| Reduced medical care costs                           | \$41                                   | \$43                                    |
| Reduced cognitive damage                             | \$184                                  | \$193                                   |
| Non-monetized health benefits††                      | H <sub>2</sub>                         | H <sub>3</sub>                          |
| TOTAL BENEFITS                                       | \$1,229+H <sub>1</sub> +H <sub>2</sub> | \$1,395+H <sub>1</sub> +H <sub>3</sub>  |
| NET BENEFITS                                         | \$786+H <sub>1</sub> +H <sub>2</sub>   | \$704+H <sub>1</sub> +H <sub>3</sub> -D |

\* This option would make a low lead gasoline (0.10 grams of lead per gallon) available only for those few vehicles that require some lead. It assumes no misfueling.

\*\* All lead in gasoline would be banned by 1988.

† These include chronic health effects of ozone and CO, and any effects of reduced sulfate particulates.

†† Since medical costs and cognitive damage were only monetized for children with high blood lead (>30 ug/dl), H<sub>2</sub> and H<sub>3</sub> represent other benefits for this group (pain, lost work time to parents, etc.) as well as all the benefits (medical, cognitive, behavior, etc.) for the lower lead group (<30 ug/dl). H<sub>2</sub> and H<sub>3</sub> differ because the numbers of children at risk under the two options differ.

#### D. THE LINGERING ISSUES

##### 1. The Properties of Lead as an Engine Lubricant

The prospects of a total ban on leaded gasoline has aroused some contention about the function of lead as a lubricant which reduced engine valve wear. The prospect of a total ban on lead has worried many who fear that older cars and heavy-duty vehicles will be damaged by unleaded fuel.

This fear rests partly on research now nearly 15 years old. In its March 1984 study on the costs and benefits of reducing lead, EPA reviewed several studies carried out on light-duty vehicles in the early 1970s. One study found essentially no wear at lead levels as low as 0.2 gpg. Another study, which sought to discover the threshold at which valve recession would occur found no wear at 0.07 gpg, but excess wear at 0.04 gpg. The conclusion was that wear would begin to occur at levels somewhere between 0.04 and 0.07 gpg. <sup>16/</sup> However, EPA noted that:

Since 1971, the automobile industry has used induction hardened valve seats, seat inserts, or chrome or nickel plating in light-duty vehicles to mitigate valve recession without lead. Essentially, these technologies either stop the oxidation of the iron valve seat or harden the valve seat (or face) to protect against the adhesive and abrasive processes. By 1971, General Motors Corporation was using this improved metallurgy on all its light-duty vehicles to compensate for the use of unleaded gasoline. Ford made these improvements on most of its light-duty vehicles by 1971 as well. After that date, other manufacturers also implemented these changes. By the 1975 model year, virtually all cars were 'clear fuel tolerant,' although the changes in light trucks may have been slower. The widespread use of these improvements since the early 1970s has greatly limited the number of vehicles that might be at risk of valve damage due to the unavailability of leaded gasoline. <sup>17/</sup> (emphasis added)

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<sup>16/</sup> See: Costs and Benefits of Reducing Lead . . . , op. cit., p. III.37.

<sup>17/</sup> Ibid., p. III.38.

EPA reviewed other categories of vehicles (other than light-duty) which might require some trace of lead. Manufacturers of small utility vehicles (e.g., lawnmowers, snowmobiles, garden tillers, etc.) indicated to the agency that these vehicles could use either fuel, but that unleaded was recommended because it would cause fewer deposits and corrosion to engines. The response from manufacturers of marine engines was inconclusive; EPA concluded that "some, but not all, marine engines would require leaded gasoline." 18/

The greatest risk of valve damage from operation solely on unleaded fuel appears to rest with vehicles operated for longer periods of time under heavy loads: trucks and farm machinery. However, the additional margin of risk from unleaded fuel is difficult to properly assess because heavy-duty vehicles tend to have longer operating lives and are likely to show eventual wear even operating on leaded fuel. As one 1971 study reviewed by EPA commented:

. . . Valve face recession and seat wear both are observed with heavy duty engines running on leaded fuel today. Wear rates are low, however, and recession is noticed only because of the extended operating life of these engines. Some increase in wear rates might occur when these engines are switched to lead-free gasoline, but catastrophic wear is not expected. 19/ (emphasis added)

Nonetheless, the EPA studies quantified with the best available data and most reasonable estimates the number of vehicles which might be at risk if an outright ban on leaded gasoline were instituted in 1988. The EPA estimates take into account the number of pre-model year (MY) 1972 vehicles likely to remain in the fleet lacking the improved valve technology instituted after 1971, as

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18/ Ibid., p. III.40.

19/ Giles, W. S. (TRW, Inc.), Valve Problems with Lead Free Gasoline, Society of Automotive Engineers Paper no. 710368, cited in: Costs and Benefits of Reducing Lead. . . . op. cit., p. III.41.

well as a certain volume of MY72 and later vehicles that might also lack improved valves (see next page).

However, by the late winter of 1985, EPA was beginning to discount the risk to engines from running unleaded fuel. Acknowledging that its review of laboratory studies conducted between 1969 and 1971 prompted the agency to propose a 0.1 gpg standard, EPA noted in a March 1985 solicitation for comments that "several large-scale sources of data" brought to the agency's attention "indicate that valve-seat recession in actual service may not be as much of a problem as the results of certain laboratory studies would indicate." 20/ EPA noted in particular the in-use experience of the Army and Postal Service with light- and heavy-duty vehicles. The vehicles tested by the Army did include some older light-duty vehicles which presumably did not have hardened valve seats; heavy-duty commercial vehicles and armored personnel carriers included in the sample did. The Army test, completed in 1976, found no "untoward maintenance problems" associated with unleaded gasoline. The observed engine failure rate was comparable to that experienced with leaded gasoline. 21/ Postal service trucks driven 175,000 miles (a distance which would normally include one full engine rebuild) on unleaded gasoline recorded valve problems consistent with the failure experienced with the same vehicles running on leaded fuel. This was also consistent with the manufacturer's own warranty data. 22/ It has also been demonstrated that the use of unleaded fuel is likely to reduce valve-related maintenance because it is a cleaner-burning fuel and leaves less deposits on engines than does leaded fuel.

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20/ See: Federal Register, v. 50, no. 45, p. 9402.

21/ Ibid., p. 9403.

22/ Ibid., p. 9403-04.

NUMBER OF ENGINES AT RISK OF SEVERE VALVE  
RECESSION WITHOUT LEADED GASOLINE

| <u>Thousands of Vehicles in 1988</u> |                   |                  |
|--------------------------------------|-------------------|------------------|
| <u>Type of Vehicle</u>               | <u>High Risk*</u> | <u>Low Risk*</u> |
| Cars Pre-'71                         | 2,240             | --               |
| LDT† Pre-71                          | 1,146             | --               |
| Cars 1971-1980                       | --                | 3,700            |
| LDT† 1971-1975                       | --                | 7,505            |
| Heavy-Duty Trucks                    | 10,865**          | --               |
| Boats                                | Not calculated    | Not calculated   |
| TOTAL "AT RISK" GROUP:               | 14,251            | 11,205           |

TOTAL ALL VEHICLES: 25,456,000

\* The "high risk" group represents heavy-duty and those light-duty vehicles manufactured before 1971. While many vehicles manufactured between 1971-1980 were built to use leaded gasoline, most of these have newer more durable valve and valve seat materials and thus for a "low risk" group.

\*\* This is equal to 30 percent of our projection of light trucks in 1988--the same proportion as was found in the Bureau of the Census publication 1977 Census of Transportation (1980).

† Light-duty trucks.

For the most part, then, it would appear that the risks from unleaded gasoline to the older engine population at large are marginal. However, for lack of data to the contrary, the magnitude of risk to special-purpose heavy-duty vehicles and marine engines is still unclear. In promulgating the 0.1 gpg standard, EPA observed that:

. . . [A]lthough there is not enough information to rule out completely the possibility that there will be some unquantifiable risk of some damage to certain engines, there are no specific data clearly demonstrating that more than 0.10 gpg is necessary for valve protection, and the potential risk of valve damage appeared to be very small. In any event, that potential risk, even if it were verifiable, would not change EPA's conclusion that 0.10 gpg is the most appropriate standard for achieving the paramount public health goals in this rule--especially in light of the clear and substantial public health risks that would be created by a more lenient standard than 0.1 gpg. 23/

Legislation has been introduced in the 99th Congress to require formal study of possible damage to farm vehicles and other heavy-duty machinery from a switchover to unleaded fuel. EPA will be initiating such a study in 1986 with results anticipated in early 1987, and no decision will be made to eliminate lead altogether from gasoline until the study is completed.

## 2. The Lead Phasedown and U.S. Oil Vulnerability

Due to a number of contributing factors, including reduced petroleum demand, a number of smaller U.S. refineries have closed during the past few years. Most of these have been independent, non-integrated refineries, whose trade associations have warned that the rash of refinery closings is leading to a structural dependency upon imported petroleum products and increasing the Nation's vulnerability once again to future disruptions. Petroleum product imports from abroad

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23/ See: Federal Register, v. 50, no. 45, Mar. 7, 1985. p. 9388.

have been cited as a major threat; a number of independent refiners urged Congress during the summer of 1985 to impose a tax or quota on product imports. Proponents of import fees or quotas also argued a worst case analysis that a further erosion in U.S. refining capacity might even leave the Nation without adequate capacity to refine crude from the Strategic Petroleum Reserve during a severe interruption. <sup>24/</sup>

Opponents of the lead phasedown have warned that the phasedown will add to the strains upon refineries already operating at the margin, and may prompt additional refinery closings, adding to U.S. vulnerability over the long-term. This is a further, but probably comparatively minor difficulty for an industry beset with major problems. Marketers and integrated refiners argue that the refineries at risk are smaller and less efficient, and should not be shielded from any vagaries in prevailing markets. Further, many of the integrated oil companies have some partnership in refineries abroad precisely because it is sometimes less expensive to import product than to refine the marginal barrel domestically.

The reduction this past January 1 to 0.1 g/gal is unlikely to have any immediate negative consequences. Because refiners reduced lead levels in early 1985--in anticipation of an announcement by EPA--many refiners have "banked" lead credits, and these may be drawn upon during 1986 in lieu of reducing their gasoline pool to 0.1 g/gal. The lead pool during 1986 will

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<sup>24/</sup> For a complete development of this particular argument, see the paper by Dr. Hossein Tahmassebi, Chief Economist, Ashland Oil, Inc., "The Outlook for Petroleum Product Imports into the United States and Their Impact on the Use of Strategic Petroleum Reserve in the 1990s," presented before the Workshop on the Strategic Petroleum Reserve, National Research Council, National Academy of Sciences, April 1985. See also: Pace Company Consultants and Engineers, Inc. The Effect of Increasing Petroleum Products Imports on the United States Refining Industry. Prepared for Independent Refiners Coalition. June 1985.

probably average around 0.3-0.5 g/gal of lead, declining to 0.1 g/gal by the end of 1987. <sup>25/</sup> To the extent that refineries continue to close, the phasedown is likely to be only a modest contributing factor. <sup>26/</sup> However, the lead phasedown does have important implications for refineries, which will be discussed in the following chapter.

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<sup>25/</sup> Grupa, L. Michael, Paul W. Fields, and Gary L. Yepsen. Octane Squeeze Won't Support Capital Investments. Oil and Gas Journal, Feb. 10, 1986. p. 98-101

<sup>26/</sup> For a more detailed discussion of the refining industry, see: U.S. Library of Congress. Congressional Research Service. Problems Facing U.S. Refiners. Report 85-931 ENR, by David Lindahl. Washington, July 15, 1985.

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## II. THE IMPACT OF LEAD PHASEDOWN (PHASEOUT) ON THE REFINING INDUSTRY\*

A. BACKGROUND AND PHYSICAL PARAMETERS

Faced with a significant phasedown in the use of lead in gasoline, the petroleum refining industry is in the process of seeking alternative ways to boost octane. The impact of the EPA ruling reducing gasoline lead content to 0.1 g/gal on January 1, 1986, has varied depending largely on the extent to which individual refineries were equipped or prepared for the change, and/or were able to bank lead rights. Some refiners were in a reasonably good position to meet the challenge of less favorable economics of lead substitutes or more capital-intensive refining processes. Other refiners, who were already operating at a narrow profit margin, are in greater difficulty. The fallout from this change will not only impact refiners, but also will affect, to some extent, related industries such as oil and gas production, gas processing, and petroleum products retail marketing. <sup>27/</sup> This fallout may also provide an opportunity for the alcohol fuels industry.

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\* By James E. Melke, Specialist in Science and Technology, Science Policy Research Division.

<sup>27/</sup> Smith, L. Douglas. Lead-phasedown Problems not Restricted to Refiners. Oil and Gas Journal, June 24, 1985. p. 95-97.

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Due to the rapid phasedown schedule, adjustments to the new lead restrictions have caused some disruptions in pricing patterns as the refining industry has sought new octane enhancing components in place of traditional blending agents. For example, refiners will now have less use for lower octane components such as butane and natural gasoline, whereas they will need a greater volume of higher octane aromatics, thus creating economic pressure on downstream chemical users. As a consequence, this led to a rapid price increase in toluene and, to a lesser extent, other aromatics in 1985 that stabilized once production began to catch up. This chapter looks at the refining industry with particular reference to how gasoline is made and what changes are likely in octane enhancement technology.

The gasoline fuels industry is subject to a number of regulatory and competitive forces that continuously keep refiners decisions regarding octane enhancement under changing and often conflicting pressures. The gasoline refining industry ranges from a few very large, highly integrated, full product-line producers to a larger number of smaller producers, many of whom produce only leaded gasoline. EPA regulates the use of octane-enhancing compounds and classes of compounds in gasoline. While all the producers are now required to meet the same octane requirements, how they choose to do so can be substantially different from producer to producer. Highly integrated producers will likely find it more attractive to provide their own octane components through a variety of enhanced refining operations. The smaller nonintegrated producers will have to rely on purchased octane components, so long as these are available. Furthermore, there is significant market opportunity for firms that develop and gain approval for proprietary octane boosters. Thus, the economics of octane improvement are not simple, and are determined by several manufacturing cost

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elements in addition to being impacted by Government regulations. Consequently, each member of the refining industry will have its own octane component production and purchasing strategy.

#### 1. The Octane Factor

Before beginning a discussion of the impact of lead phasedown on the refining industry, it would be useful to review what octane is and what lead does for gasoline. Of all gasoline characteristics, none is more crucial to engine operation and longevity than octane rating. At the same time, there is probably no aspect of gasoline quality more widely misunderstood.

The efficiency of an internal combustion engine operating on the Otto cycle <sup>28/</sup> is directly related to its compression ratio. Higher compression ratios yield greater efficiency. Theoretically, an increase of compression ratio from four to eight would result in a 33 percent increase in efficiency. Gasolines, however, auto-ignite at high compression ratios before the controlled, spark-initiated flame front can envelop the entire combustion chamber. The resultant uncontrolled explosive combustion is called engine knock, which can be mechanically damaging to the engine by occurring too soon before the valves and pistons are at the proper points in their cycles. Every spark ignition engine fuel will cause knock at or beyond some critical compression ratio. One way to overcome this premature self-ignition and thereby increase compression ratios is to add materials that resist self-ignition. These compounds are called, variously, octane boosters, octane enhancers, antiknock additives, etc., and by definition "octane" becomes a measure of the ability of an automotive gasoline to resist premature ignition. It is not, as it is commonly assumed

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<sup>28/</sup> The basic thermodynamic cycle for the prevalent automotive type of internal combustion engine.

to be, a measure of power. It does not provide any direct indication of the power that an engine will develop or of the fuel economy that it may achieve.

Octane rating is based on two similar standardized tests, both performed on the same standardized, single cylinder test engine. The tests measure what is termed the Research octane number (RON) and the Motor octane number (MON). The MON test is run at more severe operating conditions, which favor knock, and, consequently, the MON is typically lower than the RON.

A third octane rating is commonly used, the Antiknock Index (AKI). The AKI is simply the numerical average of the Research and Motor octane numbers expressed as follows:

$$AKI = \frac{RON + MON}{2}$$

The AKI is used to standardize the octane numbers advertised by gasoline marketers and is the number displayed on gasoline pumps.

A fourth octane rating, the road octane number (RdON) is also measured by the automotive and petroleum industries in order to help match octane ratings with vehicle requirements. This rating is measured in a vehicle operated on the road employing standardized test procedures, and the result depends on the vehicle, operating conditions, and fuel. In general, for late model vehicles, the RdON ratings tend to correlate closely with the AKI.

Octane numbers are assigned relative to two primary reference fuels. These fuels are 2, 2, 4-trimethyl pentane (iso-octane) and normal heptane (n-heptane). These fuels have arbitrarily been assigned octane ratings of 100 and 0 respectively. For example, a gasoline measured against these standards might have an octane rating (knocking tendency) of 87 which would be equivalent to a mixture of 87 percent iso-octane and 13 percent n-heptane.

The octane rating of a gasoline is determined by the individual octane values of its various components. Components or refinery streams with high octane values are blended with the base fuel gasoline-range hydrocarbons to raise the octane rating of the gasoline. However, the octane value response of a gasoline to the addition of an octane-boosting component is not necessarily in direct proportion to the amount of the component added. Because of interactions between hydrocarbons, the octane-boosting component may have an apparent or blending octane value (BOV) considerably different from its octane rating as a pure fuel. This effect is illustrated in table 2 which gives the average blending values and pure hydrocarbon octane ratings for several hydrocarbons in gasoline. The effect of lead in enhancing octane rating is also shown.

The concentration of the octane-boosting component typically affects its blended octane value. In general, BOVs tend to be highest at low concentrations and decrease somewhat as the octane-boosting additive concentration increases. The BOV of hydrocarbon components also depends on the composition of the fuel to which they are added. This dependence is usually not strong in the case of hydrocarbon components added to all-hydrocarbon base fuels, but can be stronger in the case of oxygenated additives in hydrocarbon base fuels. In an integrated refinery producing many different products, continuous octane monitoring of blendstocks is essential to utilize best the materials available and to maximize the economics of the refiner operations.

Before the lead phasedown began, gasoline octane ratings were achieved by a combination of lead additives and increased processing severity. Since the discovery of tetraethyl lead (TEL) in 1923, lead alkyls have been used to boost octane. Their effectiveness is unexcelled. With lead antiknock

TABLE 2. Average Octane Blending Values of  
Pure Hydrocarbons in Gasoline  
(Values in parentheses are estimated)

|                           | Average Blending Values |      |                            |      | Octanes: Pure Hydrocarbons |       |                    |       |
|---------------------------|-------------------------|------|----------------------------|------|----------------------------|-------|--------------------|-------|
|                           | Unleaded Gasoline       |      | Leaded Gasoline, at 2 g Pb |      | Unleaded                   |       | 3.17 g Pb/gal. TEL |       |
|                           | RON                     | MON  | RON                        | MON  | RON                        | MON   | RON                | MON   |
| <b>Paraffins</b>          |                         |      |                            |      |                            |       |                    |       |
| Propane                   | (112)                   | (97) | 116                        | 105  | 112                        | 97    | (123)              | (124) |
| Isobutane                 | (101)                   | (98) | 113                        | 109  | 101                        | 98    | (112)              | (109) |
| n-butane                  | 94                      | 89   | 104                        | 104  | 94                         | 90    | 104                | 104   |
| Isopentane                | 91                      | 87   | 102                        | 100  | 92                         | 90    | 109                | 104   |
| n-pentane                 | 80                      | 86   | 79                         | 88   | 82                         | 83    | 86                 | 84    |
| 2, 3-dimethyl butane      | 103                     | 95   | 111                        | 107  | 104                        | 94    | (119)              | 112   |
| 2-methyl pentane          | 73                      | 78   | 87                         | 94   | 73                         | 74    | 93                 | 91    |
| 3-methyl pentane          | 73                      | 74   | 89                         | 91   | 75                         | 74    | 93                 | 91    |
| n-hexane                  | 42                      | 49   | (85)                       | (75) | 25                         | 26    | 65                 | 65    |
| 2, 4-dimethyl pentane     | 86                      | 85   | 97                         | 90   | 83                         | 84    | 97                 | 99    |
| 3-methyl hexane           | 58                      | 69   | 81                         | 84   | 52                         | 56    | 75                 | 81    |
| 2, 2, 4-trimethyl pentane | 100                     | 94   | 106                        | 106  | 100                        | 100   | 116                | 116   |
| n-heptane                 | 13                      | 23   | 30                         | 42   | 0                          | 0     | 44                 | 47    |
| 2, 2, 5-trimethyl hexane  | 91                      | 90   | 104                        | 104  | (92)                       | (96)  | (104)              | (112) |
| n-octane                  | -17                     | -1   | 30                         | 41   | (-38)                      | (-38) | (6)                | (9)   |
| n-decane                  | -33                     | -21  | 19                         | 28   | (-57)                      | (-57) | (-13)              | (-10) |
| <b>Olefins</b>            |                         |      |                            |      |                            |       |                    |       |
| 2-methyl-2-butene         | 111                     | 88   | 107                        | 79   | 97                         | 85    | 99                 | 86    |
| 2-methyl-1-pentene        | 90                      | 79   | (87)                       | (74) | 94                         | 81    | 100                | 85    |
| 1-hexene                  | (74)                    | 47   | (86)                       | (64) | 76                         | 63    | 92                 | 76    |
| diisobutylene             | 125                     | 96   | 112                        | 90   | 105                        | 89    | 109                | 90    |
| <b>Naphthenes</b>         |                         |      |                            |      |                            |       |                    |       |
| methyl cyclopentane       | 83                      | 77   | 96                         | 92   | 91                         | 80    | 105                | 93    |
| methyl cyclohexane        | (71)                    | (89) | (83)                       | (85) | 75                         | 71    | 88                 | 86    |
| <b>Aromatics</b>          |                         |      |                            |      |                            |       |                    |       |
| benzene                   | 106                     | 88   | 112                        | 92   | -                          | -     | -                  | -     |
| toluene                   | 114                     | 93   | 116                        | 98   | 120                        | 104   | (128)              | 112   |
| ethyl benzene             | 118                     | 99   | 114                        | 95   | 107                        | 98    | 107                | 103   |
| p-xylene                  | 120                     | 98   | 115                        | 99   | 116                        | 110   | (126)              | 119   |
| m-xylene                  | 120                     | 99   | 116                        | 99   | 118                        | 115   | 120                | 120   |
| o-xylene                  | 109                     | 87   | 83                         | 85   | (102)                      | 100   | (100)              | 100   |
| isopropyl benzene         | 115                     | 99   | (106)                      | (91) | 113                        | 99    | 118                | 105   |
| n-propyl benzene          | 115                     | 100  | (106)                      | 93   | 111                        | 99    | 118                | 113   |
| 1,2,4-trimethyl benzene   | 118                     | 92   | (97)                       | 83   | 111                        | 106   | 112                | 108   |

Source: Gasoline Octane Enhancement: Technology, Economics, and Environmental, Health and Safety Considerations. Prepared for U.S. Dept. of Energy, Office of Environmental Analysis, by Mueller Associates, Inc., DOE/PE/72013-1, Washington, D.C., July 1985, p. IV-3.

usage now being essentially phased out, refiners must turn to increased processing severity or other additives such as oxygenated fuels. Blending octane values of several oxygenates and tetraethyl lead are given in table 3.

TABLE 3. Blending Values of Octane Improvers

| Compound                     | RVP, psi | Blending Octane |        |           |
|------------------------------|----------|-----------------|--------|-----------|
|                              |          | RON             | MON    | (R + M)/2 |
| Methanol                     | 40       | 135             | 105    | 120       |
| Ethanol                      | 11       | 132             | 106    | 119       |
| tert-Butanol (TBA)           | 6        | 106             | 89     | 98        |
| MTBE                         | 9        | 118             | 101    | 110       |
| Diisobutylene (DIB)          | 2        | 120             | 95     | 108       |
| tertiary Butyl Formate (TBF) | 6        | 116             | 96     | 106       |
| TEL                          | —        | 10,000          | 13,000 |           |

SOURCE: Gary, James H., and Glenn E. Handwerk. *Petroleum Refining, Technology and Economics*, 2d ed. Marcel Dekker, Inc., New York, 1984. p. 195.

The blending value of pure TEL is clearly impressive. Aside from their antiknock qualities, lead alkyls also serve as valve seat lubricants. In this regard, there is at least some concern whether 0.1 g/gal will be sufficient to protect the valve seats of engines designed for leaded fuel (see chapter I). Also apparent in table 3 is the excellent BOV of methanol and ethanol.

## 2. Vapor Pressure

Another important consideration in gasoline blending is vapor pressure. Gasoline consists of a mixture of hydrocarbon compounds generally containing from four to eleven carbon atoms. Consequently, gasoline exhibits a boiling temperature range, rather than a unique boiling point of a pure compound. By specification, the high end of the boiling temperature range, by which all

of the gasoline must vaporize, is 440 degrees F. The initial boiling temperature is generally in the range of 80 to 90 degrees F, and is adjusted to accommodate seasonal temperature variations (more volatile gasoline is needed in cold weather for ease of starting, less volatile gasoline in warm weather to help prevent vapor lock). The Reid vapor pressure (RVP) is a measure that characterizes the beginning of the distillation curve or the volatility of the lightest, most readily vaporized portion of the fuel. Gasoline must meet volatility specifications based on the Reid vapor pressure. Table 4A lists the volatility specifications set by the American Society for Testing and Materials (ASTM D 439) for the five classes of gasoline marketed in the United States. The Reid vapor pressure is measured at 100 degrees F and,

TABLE 4. Volatility Specifications for Gasoline

| Gasoline Volatility Class | Reid Vapor Pressure, psi (kPa), max | Distillation Temperatures, °C(°F), at Percent Evaporated <sup>a</sup> |          |           |           |               | Dist. Residue, % max | Vapor/Liquid Ratio       |         |
|---------------------------|-------------------------------------|-----------------------------------------------------------------------|----------|-----------|-----------|---------------|----------------------|--------------------------|---------|
|                           |                                     | 10 max                                                                | 50       |           | 90 max    | End Point max |                      | Test Temperature, °C(°F) | V/L max |
|                           |                                     |                                                                       | min      | max       |           |               |                      |                          |         |
|                           |                                     |                                                                       |          |           |           |               |                      |                          |         |
| A                         | 9.0 (62)                            | 70 (158)                                                              | 77 (170) | 121 (250) | 190 (374) | 225 (437)     | 2                    | 60 (140)                 | 20      |
| B                         | 10.0 (69)                           | 65 (149)                                                              | 77 (170) | 118 (245) | 190 (374) | 225 (437)     | 2                    | 56 (133)                 | 20      |
| C                         | 11.5 (79)                           | 60 (140)                                                              | 77 (170) | 116 (240) | 185 (365) | 225 (437)     | 2                    | 51 (124)                 | 20      |
| D                         | 13.5 (93)                           | 55 (131)                                                              | 77 (170) | 113 (235) | 185 (365) | 225 (437)     | 2                    | 47 (116)                 | 20      |
| E                         | 15.0 (103)                          | 50 (122)                                                              | 77 (170) | 110 (230) | 185 (365) | 225 (437)     | 2                    | 41 (105)                 | 20      |

<sup>a</sup>At 101.3 kilopascals pressure [kPa, or 760 millimeters mercury (mmHg)].

as mentioned, is adjusted seasonally. The RVP usually is adjusted by adding or withdrawing butanes from the gasoline pool. Butanes are volatile and also have a moderately high octane value. (For n-butane the RVP is 52 and the BOV is 92.) Since butane is produced in refining operations and has a much higher value when marketed in gasoline than it does otherwise, a refiner tries to use as much butane in gasoline as he can and still meet volatility standards.

Volatility is also a factor affecting the potential for increased use of methanol in gasoline. The high volatility of methanol has been of particular concern to EPA in its efforts to maintain air quality, and is one of the reasons that methanol is not approved for use as a gasoline blendstock except in certain specific formulations. Gasolines have a RVP in the range of 9 to 15 psi, whereas the RVP of methanol is 40. However, when blending low-molecular-weight alcohols with nonpolar liquids, such as hydrocarbons, the apparent volatility of the alcohol increases. For methanol this increase is greatest, and the blending RVP of methanol starts at around 64. On the other hand, the vapor pressure blending effect of alcohols is nonlinear and drops rapidly as their concentration is increased. Thus, additions of alcohol above 3 percent have little further effect on vapor pressure, and the overall effect for methanol would be to raise the RVP of an average gasoline blend by about 3 psi. <sup>29/</sup> This would still mean that in order to meet RVP specifications using methanol as a blendstock it would be necessary to remove other volatile gasoline components, such as butane. This becomes, then, a cost or economic disincentive to the refiner because he must market his butane at a lower return than it would yield in gasoline.

The following section contains a brief description of the refining process with emphasis on gasoline production. Production of gasoline accounts for about 45 percent of the crude oil consumption in the United States. On the basis of volume, gasoline is the single most important petroleum product manufactured in this country.

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<sup>29/</sup> Unzelman, George H. Problems Hinder Full Use of Oxygenates in Fuel. Oil and Gas Journal, July 2, 1984. p. 59-65.

## B. HOW GASOLINE IS MADE

As it comes out of the ground, crude oil has never been of much practical use. In a modern refinery, this unpretentious raw material can be converted into hundreds of different products and chemicals, many of which are themselves feedstocks and building blocks for countless other products. The refining process involves four basic steps: separating, converting, treating, and blending. Using heat, the refiner separates crude oil into fractions based on boiling temperature range. The raw fractions are then converted into more desirable intermediates by splitting or rebuilding the hydrocarbon molecules. These base stocks are then treated to remove sulfur, heavy metals, and other impurities and finally are blended together with various additives to produce the desired products.

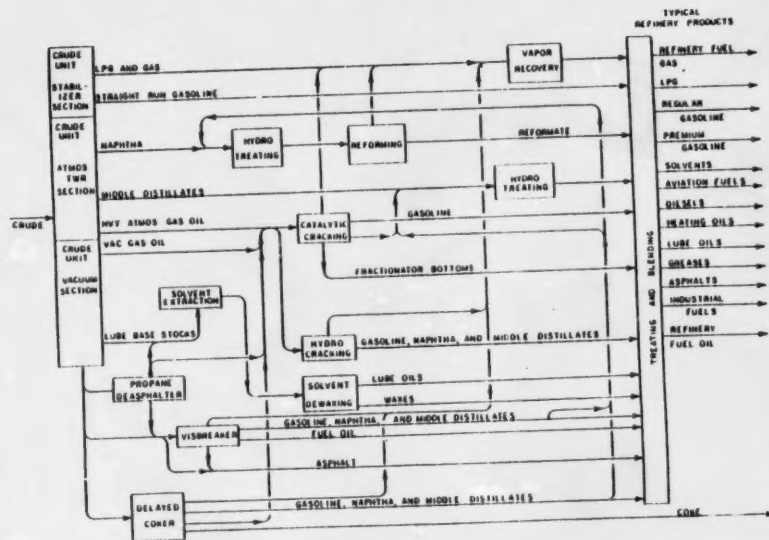
Each refinery has its own unique processing scheme which is determined by the equipment available, characteristics of the crude oil, operating costs, and product demand. The optimum flow pattern for any refinery is dictated by economic considerations, and no two refineries are identical in their operations. Figure 1 shows a generalized processing sequence in a modern refinery, indicating major process flows between operations.

### 1. Separating

Crude oil is a mixture of many chemical compounds, predominantly hydrocarbons. One of the first steps in refining is to separate the various groups of compounds. The principal separating procedures are atmospheric and vacuum distillation. Prior to distillation, crude oil is first desalted and dewatered.

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FIGURE 1. Refinery Flow Diagram



SOURCE: Gary, James H., and Glenn E. Handwerk. Petroleum Refining, Technology and Economics, 2d ed. Marcel Dekker, Inc. New York, 1984. p. 3.

The salt and water come from brines associated with crude oils, and if not removed, will contribute to fouling and corrosion of heat exchangers and other process equipment.

The crude oil is then passed through a furnace or pipe still where it is vaporized and passed on to the atmospheric fractionating tower. The vapors rise in the tower, cooling as they ascend. As each compound cools below its boiling point, it condenses. Compounds with similar boiling points are collected and drawn off in five or six separate fractions such as fuel gas, straight run gasoline, naphtha, middle distillates, and light and heavy gas oils. The unevaporated liquids are transferred to a vacuum distillation tower where they are heated and vaporized under reduced pressure. Again several product fractions are drawn off.

## 2. Converting

Straight-run gasoline 30/ is used directly in gasoline blending or is processed in an isomerization unit to improve octane before blending. The isomerization process converts normal (straight-chain) paraffins into their isomers (branched chains) by using heat and special catalysts. This results in a significant octane increase. For example, n-pentane has a RON of 61.7 whereas its isomerized cousin, isopentane, has a rating of 92.3. In once-through isomerization, the RON of straight-run gasoline can be increased from 70 to 82. 31/ Some isomerization units are also used to convert butane into isobutane which is needed in the alkylation process described later.

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30/ Also commonly referred to as light straight-run (LSR) naphtha. Straight-run gasoline consists mainly of five- and six-carbon paraffins.

31/ Gary, James H. and Glenn E. Handwerk. Petroleum Refining. Technology and Economics, 2d ed., Marcel Dekker, Inc., New York, 1984. p. 87.

The naphtha fraction is a major ingredient of gasoline. However, it too needs to be raised in octane value. This is done in the reformer. Naphtha is transferred from the distillation units, revaporized, and the gases are placed under pressure in the reactor vessel. A catalyst causes the larger, low-octane molecules to lose some of their hydrogen atoms and reform into smaller, higher-octane molecules. Hydrogen is produced as a by-product. The product stream is cooled in a heat exchanger and the liquid naphtha is separated from the hydrogen gas. The high-octane product, called reformate, contains large proportions of aromatic (ring structure) hydrocarbons which give it a high octane value. Reformate is one of the most important high-octane blending components of gasoline.

Fluid catalytic cracking (FCC) units split large molecules in the gas oil boiling range (see figure 1) into smaller molecules in the naphtha and heating oil boiling range. The catalyst is a very fine powder which is handled as if it were a fluid. The fluidized catalyst is circulated continuously between the reaction zone and the regeneration zone. Incoming gas oil and recycled liquids are pumped into the reactor vessel where they mix with the superhot regenerated catalyst. The heat from the catalyst vaporizes the feed and brings it up to reaction temperature. As the molecules crack the vapors are drawn off and separated by routine fractionation. In the reaction, coke (almost pure carbon) forms on the catalyst and deactivates it. The coke is burned off the spent catalyst in the regeneration zone, thereby reactivating and superheating the catalyst for recycling. The product streams are either used directly for fuels blending or processed further. Two further processing steps commonly used to increase gasoline yields and octane values are hydrocracking and alkylation.

In a modern refinery, catalytic cracking and hydrocracking work as a team. The fluid catalytic cracker takes the more easily cracked light gas oils as charge stocks, while the hydrocracker uses heavy gas oil fractions as feed. Hydrocracking is a combination of catalytic cracking and hydrogenation. The heavy gas oil feed is mixed with hydrogen, heated, and passed through a reaction vessel containing a fixed bed catalyst. The process cracks the large molecules into smaller, lighter molecules, thus increasing the volume of the product (called hydrocrackate). Excess hydrogen is removed and recycled. The liquid is fractionated and the heavy bottoms are again mixed with hydrogen and recycled or passed through a second stage reactor. The reaction process yields butane, light hydrocrackate, heavy hydrocrackate, and compounds in the heating oil boiling range. When operating hydrocrackers for total conversion of distillate feeds to gasoline, the butane and heavier liquid yields are generally around 120 percent of the volume of the feed.

In a sense, alkylation works in the opposite direction from hydrocracking by joining two small molecules of gas into one larger molecule of high octane liquid called alkylate. Olefins (hydrocarbon chains with at least one double bond) and isobutane are used as the alkylation unit feedstocks. Olefins can be produced by removing hydrogen from paraffins. The chief sources of olefins are catalytic cracking and coking operations. Isobutane is obtained mainly from hydrocrackers and catalytic crackers, but is also obtained from reformers, crude distillation units, natural gas processing, and, in some cases, from isomerization units. In the alkylation process, the gases are cooled to liquid form and mixed with acid catalyst. The resulting reaction combines the hydrocarbon molecules into branched-chain paraffins which have superior anti-knock properties. Acid is removed in a separator and recycled to the reaction vessel.

The remaining liquid is treated to neutralize traces of acid, and sent to a fractionation tower. In addition to alkylate, the distillation tower separates out isobutane and liquid propane. The isobutane is recycled and the LPG grade propane is marketed separately. Alkylate is an important blending ingredient in gasoline.

The coking process was developed to minimize refinery yields of residual fuel oil by severe thermal cracking of heavy residues from other processes, primarily vacuum distillation. After the high temperature cracks the heavy molecules, the vapors are drawn off and separated into gas, naphtha, and gas oils. The residue is essentially pure carbon or coke and is marketed as part of the product line. Coker gas is generally used as fuel elsewhere in the refinery. The naphtha and light gas oils can be sent to product blending or to the reformer to raise their octane rating. The heavier coker distillates serve as feed for the hydrocracker. A milder form of thermal cracking used on heavy residues is called visbreaking.

### 3. Treating

One process that affects nearly all refinery products is hydrosulfurization or hydrotreating. Most crude oils contain sulfur which must be reduced or removed from the final products. Hydrotreating is a catalytic process to stabilize petroleum products and/or remove objectionable elements such as sulfur, nitrogen, and trace metals from products or feedstocks by reacting them with hydrogen. Stabilization involves converting unsaturated gum-forming hydrocarbons to paraffins. When the process is applied specifically for sulfur removal it is usually called hydrosulfurization.

In the hydrotreating process, incoming feeds are mixed with hydrogen (usually obtained from reforming operations) and heated. The hot mix enters a reactor where the hydrogen combines with the oil to produce hydrogen sulfide, ammonia, saturated hydrocarbons, and free metals. The metals remain on the catalyst and the other products leave the reactor with the oil-hydrogen stream. The liquid product, now low in sulfur, is cooled and drawn off. The hydrogen sulfide is processed to recover sulfur and the remaining hydrogen is recycled.

#### 4. Blending

The last stage in the refining process is blending. Blending is the process of combining separate product streams or similar fractions derived from different processing steps into a product that meets the particular specifications such as vapor pressure, viscosity, specific gravity, sulfur content, octane number, initial boiling point, etc., of the products. Blending is used to adjust the octane rating of gasoline stocks by blending in high-octane components from the processes that yield these. The objective of product blending is to allocate the available blending components in such a way as to maximize the value of the product mix at the least cost. The volumes of products sold, even by a medium-sized refiner, are so large that savings of a fraction of a cent per gallon will amount to a significant savings over a period of one year. For example, if a refiner sells about one billion gallons of gasoline per year (several U.S. refiners sell more than that), a saving of one-tenth of a cent per gallon will increase profits by one million dollars for the year.

Many refineries today use computer-controlled in-line blending for blending gasolines and other high-volume products. Inventories of blending stocks, together with cost and physical property data are maintained in the computer. In addition, to ensure that the blended streams meet the desired specifications, analyzers for such properties as boiling point, specific gravity, Reid vapor pressure, and research and motor octane comparators are installed to provide feedback control of the additives and blending streams.

#### C. OPTIONS FOR MEETING THE LEAD PHASEDOWN--REFINERY MODIFICATIONS

Each refinery reflects a particular situation regarding available feedstock, product market, and existing processing units. Given the number of degrees of freedom in a typical refining operation, the selection of the optimum processing scheme for meeting the requirements for decreasing the amount of lead in gasoline is not simple. Octane enhancement can be achieved by many routes, but the individual refiner's strategy ultimately depends upon economics and process unit availability. However, some generalizations can be made.

One development currently affecting and aiding the ability of the refining industry to cope with the impact of lead phasedown is the current excess in refining capacity. Conservation of petroleum products has left an excess supply of crude oil and refining capacity. In the United States, demand for gasoline peaked in 1979 and has since declined, primarily because of smaller cars and improved gasoline mileage. Despite the closure of numerous refineries, most of them smaller refineries with less processing flexibility, only about 75 percent of the operating capacity of U.S. refineries is currently being used.

The result is spare processing flexibility which can be used to upgrade the octane quality of refinery gasoline pools. In particular, this allows operating certain process units under conditions which raise octane but lower output. Further, excess processing capacity allows older processing units to be shut down and modified or revamped to produce higher octane products at a lower investment cost and more rapid completion than building additional new units.

A number of specific refinery modifications available to increase gasoline pool octane are described in this section and the companies choosing each of these routes are identified. Figure 2 provides a reference illustration of most of these process options.

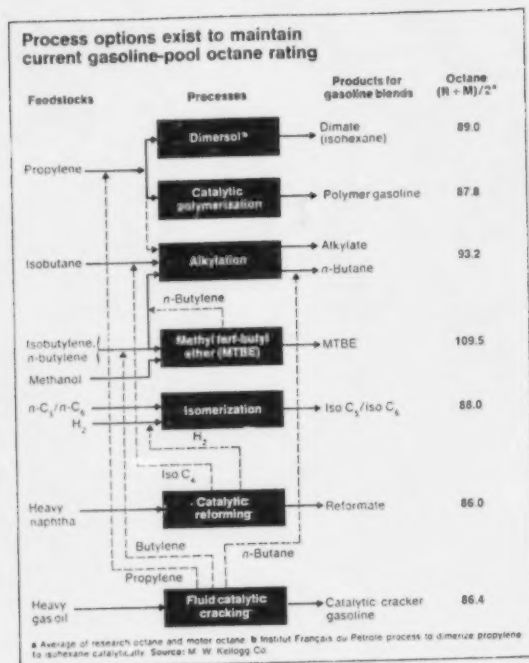
#### 1. Isomerization

Of the available alternatives to upgrade gasoline-pool octane within the constraints of lead-reduction regulations, light straight-run naphtha isomerization is among the most effective. <sup>32/</sup> For a typical U.S. Gulf Coast refinery, about 15 to 18 percent by volume of the total gasoline pool is LSR naphtha or straight-run gasoline. With total (recycle) isomerization, the AKI value of straight-run-gasoline can be raised from around 70 to about 88, resulting in an increase in the total gasoline pool of about two octane numbers. Once-through operation results in lower isomate octane, about 80 AKI, but with a savings in installation cost of about 50 percent. A modest amount of hydrogen is consumed in the isomerization process which can normally be supplied from the

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<sup>32/</sup> Schaidt, R. J., J. A. Weiszmann, and J. A. Johnson. Catalysts-- Key to Low-Cost Isomerization. Oil and Gas Journal, May 27, 1985. p. 80-88.

FIGURE 2.



SOURCE: Refiners Grappling With Lead Phasedown in Gasoline. Chemical and Engineering News, Nov. 25, 1985. p. 30-31.

reformer with virtually no impact on refinery hydrogen balance. One disadvantage of isomerization is that the catalysts employed are very sensitive to sulfur contamination. Consequently, isomerization feed must be hydrotreated to very low sulfur levels which adds to the cost of increased isomerization.

Isomerization currently is the most common process investment for coping with lead phasedown. Of the construction projects designed primarily to help meet the new lead in gasoline limits, reported to have been underway or completed in 1985 at U.S. refineries, ten involve isomerization units. The projects are listed in table 5 by company, location, and capacity (where available) in barrels per day (b/d). Several hydrotreating projects for pretreating feed, including isomerization feed, were also completed or under construction in 1985.

TABLE 5. Isomerization Projects Under Construction or Completed at U.S. Refineries in 1985

| Company            | Location                 | Capacity (b/d) |
|--------------------|--------------------------|----------------|
| American Petrofina | Port Arthur, Texas       | 8,000          |
| Amoco              | Whiting, Indiana         | 17,500         |
| Amoco              | Texas City, Texas        | ---            |
| Ashland Petroleum  | Canton, Ohio             | 6,500          |
| Kendall/Amalie     | Bradford, Pennsylvania   | 1,000          |
| Koch Refining      | Rosemount, Minnesota     | 15,000         |
| Marathon Petroleum | Garyville, Louisiana     | 12,000         |
| Marathon Petroleum | Robinson, Illinois       | 10,500         |
| Pennsoil           | Rouseville, Pennsylvania | 1,150          |
| Total Petroleum    | Ardmore, Oklahoma        | 6,000          |

SOURCE Tables 5, 6, 8, and 10: Refineries--Worldwide Construction (1984), Oil and Gas Journal, Oct. 29, 1984. p. 87-88. Refineries--Worldwide Construction (1985), Oil and Gas Journal, Oct. 21, 1985. p. 85; and Obel, Michael. U.S. Refiners Press Work on Projects at 32 Sites, Oil and Gas Journal, Oct. 28, 1985. p. 50-51.

## 2. Fluid Catalytic Cracking

Another primary candidate for octane enhancement is the fluid catalytic (FCC) unit. Blendstock from the FCC unit typically comprises 30 to 35 percent by volume of the total gasoline pool. Therefore, modest changes in this process can have a major impact on the total gasoline pool quality and production rate. In modern FCC units, gasoline octane can be improved by using new catalysts designed to enhance octane. Specially designed FCC catalysts can increase research octane number by 3 to 4 numbers and motor octane number by 1 to 1.5. <sup>33/</sup> The principal characteristics of these catalyst types are that they contain a type of aluminum-deficient zeolite framework generally called ultrastable Y (USY) or a combination of USY with shape-selective molecular sieves. Small amounts of rare Earth metals can be exchanged onto USY in order to enhance its activity. Four FCC new or revamping construction projects were completed in 1985. These are listed in table 6.

TABLE 6. FCC Projects Completed at U.S. Refineries in 1985

| Company            | Location              | Capacity (b/d) |
|--------------------|-----------------------|----------------|
| Koch Refining      | Corpus Christi, Texas | 40,000         |
| Phillips Petroleum | Borger, Texas         | 4,200          |
| Tenneco            | Chalmette, Louisiana  | 19,500         |
| Texaco             | El Paso, Texas        | ---            |

SOURCE: See table 5.

<sup>33/</sup> Magee, J. S., W. E. Cormier, and G. M. Woltermann. Octane Catalysts Contain Special Sieves. Oil and Gas Journal, May 27, 1985. p. 59-64.

### 3. Alkylation

Increasing the output of the FCC unit through new construction, revamping older equipment, or operational changes provides more olefins for alkylation. Alkylation is a common method for producing high-octane gasoline feedstocks. Currently around 11 percent of the total gasoline pool consists of alkylate (see table 7). Alkylate was favored in the

TABLE 7. Gasoline Production and Composition of the Motor Gasoline Pool

|                                             |                 |
|---------------------------------------------|-----------------|
| Installed crude capacity                    | 18,300,000 bopd |
| Operating rate (% of installed capacity)    | 75              |
| Operating motor gasoline production         | 8,329,000 bopd  |
| Crude conversion to motor gasoline, %       | 51              |
| Estimated alkylation capacity               | 829,970 bopd    |
| Estimated alkylate to motor gasoline, %     | 11              |
| Gasoline pool                               |                 |
| FCC gasoline                                | 35%             |
| Reformate                                   | 31%             |
| Alkylate                                    | 11%             |
| Straight run gasoline                       | 4%              |
| Isomerate                                   | 1%              |
| Polymer gasoline                            | 1%              |
| MTBE                                        | 1%              |
| Other components                            | 8%              |
| Butane                                      | 5%              |
|                                             | 100%            |
| Pool octane (R + M)/2 (clear)               | 86.2            |
| Butylene alkylate octane (R + M)/2 (clear)  | 83.0            |
| Propylene alkylate octane (R + M)/2 (clear) | 88.0            |

SOURCE: Chapin, L. E., G. C. Liolios, and T. M. Robertson. Which Alkylation—HF or H<sub>2</sub>SO<sub>4</sub>? Hydrocarbon Processing, Sept. 1985. p. 67-71.

past because its BOV is enhanced by the presence of lead. While removing lead from gasoline reduces alkylate's effective octane value, it is still a valuable contributor to octane enhancement. The economics of alkylation in any given refinery depend to some extent on the refiner's isobutane and olefin balances. <sup>34/</sup> Alkylate production and quality can be increased by

<sup>34/</sup> Culberson, S. F., G. L. Yepson, and K. D. Bartholomew. Refiners Mull No-Lead Options. Oil and Gas Journal, Mar. 18, 1985. p. 108-114.

newer technologies now available. Revamping existing sulfuric acid alkylation units can increase product octane by 1 to 2 RON with a reduction in acid consumption. <sup>35/</sup> In addition alkylation plants can be expanded to include propylene in the feed stream. Reactor performance can be improved to deal with propylene which would otherwise yield a lower octane alkylate (table 7), and is not now generally part of the alkylation feed.

Six alkylation projects were under construction or completed in 1985. These are listed in table 8.

TABLE 8. Alkylation Projects Completed or Under Construction at U.S. Refineries in 1985

| Company               | Location              | Capacity (b/d) |
|-----------------------|-----------------------|----------------|
| American Petrofina    | Port Arthur, Texas    | 4,900          |
| Amoco Oil             | Texas City, Texas     | 23,500         |
| Koch Refining         | Corpus Christi, Texas | 9,500          |
| Mobil Oil Corporation | Paulsboro, New Jersey | 1,300          |
| Tenneco               | Chalmette, Louisiana  | 11,000         |
| Unocal Corporation    | Lemont, Illinois      | 16,000         |

SOURCE: See table 5.

#### 4. Catalytic Polymerization

Two other processes using propylene for feed are available, catalytic polymerization and Dimersol. Catalytic polymerization converts propylene or mixed propylene and butylene feed to a moderately high-octane blending

<sup>35/</sup> Pierce, V. E., and A. K. Logwinuk. Which Route to More Octane? Hydrocarbon Processing, Sept. 1985. p. 75-79.

component. Traditionally propylene has been the preferred feed since butylenes have been used for alkylation. Feeding propylene to the catalytic polymerization process is somewhat in question because the AKI of the polymer gasoline produced is only 87.8, although the blending AKI is around 90. Increased operating severity of the FCC can yield more propylene for catalytic polymerization. Like alkylation, the economics of this process in any refinery depend on the availability of olefins and alternative values as chemical feedstocks. Overall, the amount of polymer gasoline produced from propylene is likely to be a small fraction of the refinery's gasoline pool. Available evidence suggests that no polymerization construction projects are currently underway at U.S. refineries.

#### 5. Dimersol

The Dimersol process catalytically dimerizes propylene to isohexane, producing a high-octane blending component called dimate. Because of the enhanced synergistic effects of blending dimate with other gasoline components, the blending AKI values of dimate are higher than for polymer gasoline. In addition the volumetric yield of dimate appears to be somewhat higher than the yield of polymer gasoline from catalytic polymerization. <sup>36/</sup>

#### 6. Catalytic Reforming

Although reforming is a well established process for octane enhancement, it is still worth examining for further improvement when increased gasoline

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<sup>36/</sup> Ibid.

pool octane is needed. Around 31 percent of the total gasoline pool is reformate (table 7). Incremental expansion of existing reforming facilities can be a relatively low-cost means of achieving additional octane output. Ultimately, catalytic reforming is limited by the amount of naphtha present in the crude oil and available for reforming. In addition to increasing reforming capacity to increase the volume of higher octane components, a number of process changes are possible. Older-high pressure reformers can be converted to operate at lower pressures using bimetallic catalysts containing rhenium and platinum to produce higher reformate and hydrogen yields. Coker and visbreaker naphtha can be routed to the catalytic reformer if this is not already done. Since these feeds are higher in sulfur and nitrogen, it may be necessary to increase the operating severity of the hydrotreater or change catalysts to avoid exceeding the allowable sulfur and nitrogen limits of the reformer.

Increased reforming severity is already a common practice to gain additional pool octane. Increased processing severity reduces the overall reformer output and thus presents an economic tradeoff. Table 9 illustrates the effect of increasing the severity of reformer operation to increase the RON of the reformate from 90 to 95 (lead-free basis). As can be seen from the table, more fuel and power are consumed to produce less liquid. While more gas is also produced, gas fractions cannot be blended into gasoline, but find other lower value uses. The table shows that liquid yield in the gasoline range decreases from 89.9 percent to 87.7 percent. Typically,

TABLE 9. Naphtha Reforming Yields

| Item                                   | Severity,<br>RON Clear |       |
|----------------------------------------|------------------------|-------|
|                                        | 90                     | 95    |
| Gas yield, scf/bbl charge              |                        |       |
| Hydrogen                               | 967                    | 1015  |
| Methane                                | 55                     | 73    |
| Ethane                                 | 55                     | 71    |
| Liquid yield, vol%                     |                        |       |
| C <sub>3</sub> (propane, propene)      | 3.6                    | 4.9   |
| iC <sub>4</sub> (isobutane, isobutene) | 1.8                    | 2.4   |
| nC <sub>4</sub> (n-butane, n-butene)   | 2.5                    | 3.4   |
| C <sub>5</sub> + (heavier)             | 85.6                   | 81.9  |
| RVP, psi                               | 2.7                    | 3.1   |
| RON, clear (unleaded)                  | 90.0                   | 95.0  |
| RON, +3cc/gal TEL                      | 98.4                   | 101.2 |
| MON, clear (unleaded)                  | 80.8                   | 84.1  |
| MON, +3cc/gal TEL                      | 89.2                   | 91.5  |
| Utilities Required                     |                        |       |
| Fuel, MMBtu/bbl                        | 0.285                  | 0.360 |
| Cooling water, Mgal/bbl                | 0.10                   | 0.11  |
| Power, kWh/bbl                         | 2.1                    | 2.9   |

SOURCE: Feldman, M. B., and D. G. Ragnow. Modern Gasoline Economics. Hydrocarbon Processing, Dec. 1982. p. 69-72, as reproduced in Gasoline Octane Enhancement: Technology, Economics, and Environmental Health and Safety Considerations. Prepared for U.S. Dept. of Energy. Office of Environmental Analysis, by Mueller Associates, Inc. DOE/PE/72013-1. Washington. July 1985. p. IV-6.

increasing reformer severity sufficiently to raise the reformate RON by one octane number decreases reformate volume by one percent. <sup>37/</sup>

Another process change to increase reformate output is conversion to continuous catalyst regeneration. Conversion of older fixed bed reformers to isomerization units is also of increased interest. Six construction or conversion projects at U.S. refineries to enhance or increase reforming capacity were underway or completed in 1985. These are listed in table 10.

TABLE 10. Reformer Projects Under Construction or Completed at U.S. Refineries in 1985

| Company                       | Location                 | Capacity (b/d) |
|-------------------------------|--------------------------|----------------|
| Ashland Petroleum             | St. Paul Park, Minnesota | 8,000          |
| Koch Refining                 | Corpus Christi, Texas    | 33,500         |
| Marlex Oil and Refining, Inc. | Long Beach, California   | 3,000          |
| Provident Energy              | Mobile, Arizona          | 30,000         |
| Pennzoil                      | Rouseville, Pennsylvania | 5,820          |
| Placid Refining               | Port Allen, Louisiana    | 10,000         |

SOURCE: See table 5.

#### 7. Aromatics (BTX)

Although essentially part of the catalytic reforming process, because of the attention being given them, aromatics are treated separately here.

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<sup>37/</sup> Gasoline Octane Enhancement: Technology, Economics, and Environmental, Health and Safety Considerations. Prepared for U.S. Dept. of Energy. Office of Environmental Analysis, by Mueller Associates, Inc. DOE/PE/72013-1. Washington. July 1985. p. IV-5.

Aromatics (particularly benzene, toluene, and xylene, collectively referred to as BTX) for petrochemical use are produced from the catalytic reformer by operating it at higher severity levels than has been customary for motor gasoline. For chemical use, the product from the reformer is separated into its individual components by a combination of solvent extraction, distillation, and crystallization. In addition, because of the much greater demand for benzene, the excess of toluene and xylenes over market needs can be converted to benzene by hydrodealkylation. However, with increased demand for toluene as an octane enhancing agent, there is less incentive for converting it to benzene.

With increased need for high-octane components, such as BTX, in gasoline, particularly for premium unleaded, the amount available to the chemical industry will likely decrease and become more expensive. Currently, it would appear that availability will not be the concern so much as price because of the increased/increasing reforming capacity, and shift to higher severity reforming and more efficient catalysts. Consequently, the refining industry is increasing the amount of BTX production such that both gasoline and chemical needs can probably be satisfied. According to M. G. Marbach of Shell Chemical, the marginal cost (cost of getting the last octane number) of making 91 to 92 octane premium unleaded may be as high as 2 cents per gallon. <sup>38/</sup> This translates to an increase in value of 26 to 27 cents per gallon for toluene and xylene when used for making premium unleaded gasoline. Thus, aromatics would be available to chemical users, but at an increased price. While the

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<sup>38/</sup> The Refiners' Struggle with Changing Demand. Chemical Week, Nov. 20, 1985, p. 43-49.

benzene price is not expected to increase as rapidly as toluene, the benzene market is still expected to become tight because of the reduced incentive for hydrodealkylation. 39/

Another issue regarding the increased use of BTX in gasoline is the concern over potential health effects. Benzene is a known carcinogen. Currently gasoline averages about 1.2 percent benzene and the total aromatic concentration averages about 27 percent. About 90 percent of the aromatics in gasoline are produced in the reformer or the FCC unit. Reformate contains 35 to 60 percent aromatics and FCC gasoline ranges between 15 to 35 percent aromatics. The question of potential health effects generally has been raised in the context of using other high-octane additives such as oxygenates (see following section) in place of aromatics. As might be expected, tradeoffs such as this are rarely simple to quantify. The Office of Technology Assessment has been asked to look into this issue.

Two projects were completed at U.S. refineries in 1985 to produce and extract aromatics and BTX. American Petrofina's refinery in Port Arthur, Texas brought a 13,000 b/d project on stream and Mapco completed a 17,180 b/d aromatics and BTX extraction project at its North Pole, Alaska refinery.

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39/ Halpern, L. B. and D. R. Noble. The Impact of Lead Phasedown on Aromatics and Other Chemicals. Chemical Engineering Progress, Oct. 1985. p. 39-41.

D. OPTIONS FOR MEETING THE LEAD PHASEDOWN--OXYGENATES (INCLUDING ALCOHOL)

In addition to modification or new construction of traditional refinery process units, the other options for meeting the lead phasedown requirements include the use of additives not generally produced in the conventional refining process. This section will focus briefly on the oxygenated hydrocarbons (methyl tertiary butyl ether (MTBE), tertiary butyl alcohol (TBA), ethanol, and methanol) used as fuel additives to boost octane. The use of alcohol fuels is covered more extensively in chapter III. Because of their high BOV values, oxygenates are good candidates for blending (see table 3).

EPA regulations limit the amount of oxygenated blending agents permitted in unleaded gasoline, table 11 lists the regulatory limits placed on the oxygenated additives approved for use in unleaded gasoline. Methanol is not approved for use as a stand-alone octane enhancer, primarily because of its high vapor pressure in addition to its corrosiveness to certain materials commonly used in fuel systems. Methanol is permitted for use as an additive in specific formulations containing cosolvents and corrosion inhibitors. The most recent example of a specific methanol formulation (not shown in table 9) to gain EPA approval was the subject of the so-called "Du Pont waiver" granted on January 14, 1985. The waiver approved a blendstock containing a maximum of 5 percent methanol and a minimum of 2.5 percent higher alcohol (i.e., ethanol, etc.) cosolvent, plus a proprietary corrosion inhibitor, provided volatility specifications and other requirements, such as not more than 3.7 weight percent oxygen in finished fuel, are met. Despite the waiver problems have prevented its actual use.

TABLE 11. Oxygenated Octane Components Approved for Use in Unleaded Gasoline

| Additive                                                                                                                                                            | Description                                                                                                                                 | Approved Concentration                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| ethanol                                                                                                                                                             | $C_2H_5OH$                                                                                                                                  | Up to 10 vol% in finished fuel                                                                                                                |
| Oxinol <sup>TM</sup>                                                                                                                                                | Methanol and gasoline-grade tertiary butyl alcohol (GTBA) not to exceed 1:1 by volume <sup>a</sup>                                          | 3.5 wt% oxygen in finished fuel max. (approx. 9 vol% max. depending on gasoline density)                                                      |
| Arconol <sup>®</sup>                                                                                                                                                | GTBA (contains small amounts of acetone, butanes, etc.)                                                                                     | 3.5 wt% oxygen in finished fuel, max. as a special case of Oxinol <sup>TM</sup> , above (approx. 16 vol% max., depending on gasoline density) |
| Petrocoal <sup>®</sup>                                                                                                                                              | Mixture of methanol with four-carbon alcohols not to exceed 6.5:1 by volume and a "proprietary corrosion inhibitor"                         | Up to 15 vol% total alcohols in unleaded gasoline; not more than 12 vol% methanol in finished fuel                                            |
| methyl t-butyl ether (MTBE)                                                                                                                                         | $C_5H_{12}O$                                                                                                                                | 2 wt% oxygen in finished fuel max. (approx. 11 vol% max., depending on gasoline density)                                                      |
| other aliphatic alcohols (e.g., propanols, butanols etc.) except methanol, and aliphatic ethers (e.g. methyl t-amyl ether or TAME, di-isopropyl ether or DIPE, etc) | aliphatic alcohols:<br>propanols $C_3H_7OH$<br>butanols $C_4H_9OH$ etc.<br>aliphatic ethers:<br>TAME $C_8H_{18}O$<br>DIPE $C_8H_{18}O$ etc. | 2 wt% oxygen in finished fuel, max. (volume proportion varies with alcohol/ether density and gasoline density)                                |

<sup>a</sup>Oxinol<sup>TM</sup> 30 is the designation applied to the Oxinol<sup>TM</sup> which is 30% methanol by volume.

SOURCE: Gasoline Octane Enhancement: Technology, Economics, and Environmental, Health and Safety Considerations. Prepared for U.S. Dept. of Energy. Office of Environmental Analysis, by Mueller Associates, Inc. DOE/PE/72013-1. Washington. July 1985. p. IV-8.

Other problems have also hindered the greater use of oxygenated blending agents. Pipelines will generally not accept blends containing alcohols because the lighter alcohols are hydrophilic (i.e. absorb water) and require an absolutely clean and dry system. <sup>40/</sup> MTBE is the only oxygenate generally accepted for refinery blending and subsequent transport through pipelines. Pipelines will, however, accept suboctane gasoline for transport, which allows oxygenates to be blended in at the destination. From the refiner's point of view, this provides an option for marketing suboctane gasoline. While the refiner would get fewer dollars per barrel for suboctane gasoline, he benefits from not having to incur the expense of upgrading processing or purchasing higher octane components. The extent to which refiners will exercise this option will depend on the attractiveness of the economics to the individual refinery, and the availableness and growth in the market for suboctane gasoline. The alcohol fuels industry may be a factor in expanding the market for suboctane gasoline which currently exists primarily in the Mid-west.

The primary value of oxygenates is their antiknock properties (table 3). However, in terms of the heat of combustion, oxygenated blending agents contain less energy per gallon than gasoline, as shown in table 12. To some extent, the oxygenates can be thought of as partially oxidized hydrocarbons. This suggests that these blending agents would yield fewer miles per gallon than conventional gasoline. Whether this is true or not in actual road tests is inconclusive. Much depends on how a particular study is conducted and

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<sup>40/</sup> Unzelman, George H. Problems Hinder Full Use of Oxygenates in Fuel. Oil and Gas Journal, July 2, 1984. p. 59-65.

TABLE 12. Net Heat of Combustion of Oxygenated Additives

|          | 1,000 BTU/gal. | Relative to gasoline, % |
|----------|----------------|-------------------------|
| Methanol | 56.6           | 49                      |
| Ethanol  | 75.7           | 66                      |
| TBA      | 98.7           | 86                      |
| MTBE     | 93.6           | 81                      |
| n-butane | 95.0           | 82                      |
| Gasoline | 115.4          | 100                     |

SOURCE: Unzelman, George H. Problems Hinder Full Use of Oxygenates in Fuel. Oil and Gas Journal, July 2, 1984. p. 59.

whether carburetor adjustments were able to accommodate the presence of alcohol. <sup>41/</sup>

#### 1. Ethanol

The blending octane value (BOV) of ethanol is 119, and its Reid vapor pressure is 11. The use of ethanol as a gasoline additive has grown dramatically over the past five years, not for its value as an octane booster, but largely because of the strength of Federal and State excise tax exemptions (see chapter 11 on alcohol fuels). To qualify for the Federal and State tax exemption, fuel-grade ethanol must be made from renewable resources (corn

<sup>41/</sup> See for example: Othmer, Donald F. Methanol: Fuel for Automobiles. Chemical Engineering Progress. Oct. 1985. p. 16-21.

is the primary raw material) in plants powered by nonpetroleum fuels. The domestic ethanol fuel market has grown from less than 100 million gallons in 1980 to around 650 million gallons in 1985 and is expected to reach 725 million gallons in 1986. <sup>42/</sup> Major ethanol producers in the United States are listed in table 13. Quantities of ethanol produced for motor fuel in 1985 are also indicated. While refiners could consider the entire ethanol supply base for octane enhancement, in effect, only fermentation/distillation plants would be eligible for the motor fuel tax exemptions (see chapter III). Archer Daniels Midland Company is by far the largest ethanol producer. Several oil companies are also involved in joint ventures, namely Ashland, Chevron, and Texaco. <sup>43/</sup>

## 2. Methanol

The BOV of methanol is 120 and its blending RVP starts around 64. (See discussion of vapor pressure in section A,2.) Because of its volatility and corrosiveness the use of methanol as a gasoline additive is controversial. The relatively low price of methyl alcohol compared with other gasoline additives offers a considerable economic leverage for its use. However, the economics of methanol blending requires consideration of the costs of cosolvents in the blend because of phase separation. Expectations that the use of neat (i.e. pure) methanol as a gasoline substitute would grow rapidly have proved premature, and the use of methanol blends in gasoline has been complicated

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<sup>42/</sup> McKinley, Sarah. Ethanol Enjoys Good Times, But Is There a Hangover Ahead? The Energy Daily, Aug. 21, 1985. p. 4.

<sup>43/</sup> Unzelman, Problems Hinder Full Use of Oxygenates. p. 63.

TABLE 13. Major U.S. Producers of Ethyl Alcohol

| Company                                                         | Capacity (1985 Motor<br>Fuel Production)* | Process†              | End Use                                |
|-----------------------------------------------------------------|-------------------------------------------|-----------------------|----------------------------------------|
| Archer Daniels Midland<br>Company                               | 300 (320)                                 | F/D                   | Primarily motor fuel                   |
| Texas Eastman Company,<br>Longview, Texas                       | 26                                        | E                     | Ethanol derivatives                    |
| Georgia Pacific Corporation,<br>Bellingham, Washington          | 5                                         | F/D                   | Includes motor fuel                    |
| Grain Processing Corporation<br>Iowa                            | 40                                        | F/D                   | Beverage                               |
| Midwest Solvents Company,<br>Atchison, Kansas                   | 40 (12)                                   | F/D                   | Primarily beverage,<br>some motor fuel |
| A. E. Staley Manufacturing<br>Decatur, Illinois                 | 40 (38)                                   | F/D                   | Motor fuel                             |
| South Point Ethanol,<br>South Point, Ohio                       | 60 (63)                                   | F/D                   | Motor fuel, etc.                       |
| Kentucky Agricultural Energy<br>Corporation, Franklin, Kentucky | 20 (18)                                   | F/D                   | Motor fuel, etc.                       |
| American Syn-Fuels<br>Federalsburg, Maryland                    | 8                                         | F/D                   | Motor fuel, etc.                       |
| Pekin Energy Company,<br>Pekin, Illinois                        | 60 (68)                                   | F/D                   | Motor fuel, etc.                       |
| Clinton Corn Processing Company                                 | 8                                         | F/D                   | Beverage                               |
| Union Carbide Corporation<br>Brownsville, Texas                 | 12                                        | N Butane<br>oxidation | Ethyl acetate                          |
| Union Carbide, Texas City<br>Texas                              | 120                                       | E                     | Derivatives                            |
| New Energy Co.,<br>South Bend, Indiana                          | -- (43)                                   | F/D                   | Motor fuel                             |

TABLE 13. Major U.S. Producers of Ethyl Alcohol (cont.)

| Company                                                           | Capacity (1985 Motor Fuel Production)* | Process† | End Use    |
|-------------------------------------------------------------------|----------------------------------------|----------|------------|
| Shepherd Oil,<br>Jennings, Louisiana                              | -- (20)                                | F/D      | Motor fuel |
| American Diversified,<br>Hastings, Nebraska, and<br>Hamberg, Iowa | -- (13)                                | F/D      | Motor fuel |
| Dawn Enterprises,<br>Walhalla, North Dakota                       | -- (3)                                 | F/D      | Motor fuel |

SOURCE: Adapted from Oil and Gas Journal. July 2, 1984. p. 61, and Alcohol Update Newsletter. Jan. 6, 1986. p. 3.

\* Million gal/yr. Total 1985 motor fuel production is estimated at 598 million gallons. In practice, annual production can exceed or be less than nameplate capacity which is a theoretical amount calculated from equipment design and operating criteria. † F/D (fermentation/distillation), E (ethylene hydration).

by Government regulations. One domestic automaker, Chrysler, and several foreign firms even recommend against using methanol-containing fuels in their products (see table 14).

Methanol is primarily manufactured from natural gas, but can also be made from coal or renewable resources at a higher cost. The major domestic producers of methanol are listed in table 15. The table also shows that a number of domestic producers have shut down their methanol production in the past year. This is largely in response to poor profitability, driven, in part, by increased production from abroad.

TABLE 14. Auto Makers Recommendations for Methanol Fuel Use in 1986 Models

| <u>Manufacturer</u>     | <u>Methanol Recommendation for<br/>1986 model-year vehicles</u> <u>a/</u> |
|-------------------------|---------------------------------------------------------------------------|
| <u>DOMESTIC</u>         |                                                                           |
| AMC/Renault             | Up to 5% with cosolvent and inhibitors                                    |
| Chrysler                | Not recommended                                                           |
| Ford <u>b/</u>          | Up to 5% with cosolvent and inhibitors                                    |
| General Motors          | Up to 5% with cosolvent and inhibitors                                    |
| <u>IMPORTED</u>         |                                                                           |
| Audi                    | Not recommended                                                           |
| BMW                     | Up to 3% with cosolvent                                                   |
| Honda                   | Not recommended                                                           |
| Isuzu                   | Up to 5% with cosolvent and inhibitors                                    |
| Jaguar/Rover/Triumph    | Up to 3% with cosolvent and inhibitors                                    |
| Mazda                   | Not recommended                                                           |
| Mercedes-Benz <u>b/</u> | Up to 3% (up to 15% MTBE)                                                 |
| Mitsubishi              | Not recommended                                                           |
| Nissan                  | Not recommended                                                           |
| Peugeot <u>c/</u>       | Up to 3% with cosolvent                                                   |
| Saab <u>d/</u>          | Not recommended                                                           |
| Subaru                  | Not recommended                                                           |
| Toyota                  | Up to 5% with cosolvent and inhibitors                                    |
| Volvo                   | Not recommended                                                           |
| Volkswagon <u>c/</u>    | Up to 3%; minimum 2% cosolvent                                            |

a/ All allow up to ten percent ethanol.

b/ Do not allow blends of ethanol and methanol.

c/ A change for 1986 model year.

d/ Applicable for first half of 1986 model year (test program under way).

SOURCE: Chemical and Engineering News, Aug. 19, 1985. p. 11.

TABLE 15. Shrinking U.S. Methanol Capacity

|                               | Million of Gallons |                 |
|-------------------------------|--------------------|-----------------|
|                               | January<br>1984    | January<br>1985 |
| Air Products and Chemicals    |                    |                 |
| Pensacola, Florida            | 60                 | 60              |
| Allemania Chemical <u>a/</u>  |                    |                 |
| Plaquemine, Louisiana         | 140                | 0               |
| Arco Chemical                 |                    |                 |
| Channelview, Texas            | 200                | 200             |
| Borden Chemical               |                    |                 |
| Columer, Louisiana            | 180                | 180             |
| Celanese Chemical             |                    |                 |
| Bishop, Texas                 | 160                | 160             |
| Clear Lake, Texas             | 200                | 0               |
| Du Pont                       |                    |                 |
| Beaumont, Texas               | 250                | 0               |
| Deer Park, Texas <u>b/</u>    | 200                | 200             |
| Eastman Chemical Products     |                    |                 |
| Kingsport, Tennessee          | 55                 | 55              |
| Georgia Gulf <u>c/</u>        |                    |                 |
| Plaquemine, Louisiana         | 120                | 120             |
| Monsanto Industrial Chemicals |                    |                 |
| Texas City, Texas             | 100                | 100             |
| Tenneco Polymers <u>d/</u>    |                    |                 |
| Pasadena, Texas               | 130                | 0               |
| Texaco Chemical               |                    |                 |
| Delaware City, Delaware       | 100                | 100             |
| Total                         | 1,895              | 1,175           |

a/ Joint venture of International Minerals and Chemical and Ashland Oil.

b/ Joint venture of Du Pont and National Distillers and Chemical.

c/ Georgia Gulf was formed in 1985 as part of a leveraged buyout of several Georgia Pacific commodity chemical plants.

d/ Unit on standby since 1982; permanently shut in 1984.

Source: Data Resources Inc., and companies.

SOURCE: Chemical Week, Sept. 18, 1985. p. 39.

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The largest use of methanol in the United States is in making formaldehyde, which is the starting chemical for urea and phenolic resins used in the housing industry. Another use of methanol that is expected to increase significantly is in the manufacture of MTBE. MTBE, produced by the reaction of isobutylene and methanol, is one way to use methanol indirectly in motor fuel without the problems associated with a light alcohol as a blending component. Pending a shift in Government regulation, this is expected to be the major fuel use of methanol in the near term. MTBE plants consumed about 100 million gallons of methanol in 1984, and the new MTBE capacity coming onstream in the next year could consume up to 260 million gallons of methanol annually by 1987. <sup>44/</sup>

### 3. MTBE

Methyl tertiary butyl ether is an attractive antiknock additive because its octane blending value is about 110 depending upon the gasoline blendstock. As mentioned, MTBE is produced by the direct reaction of methanol and isobutylene. Currently methanol is readily available at low prices and is expected to remain so for the foreseeable future. <sup>45/</sup> Isobutylene availability is limited to by-product or excess production from other refinery operations such as catalytic cracking, coking, and ethylene production from naphtha and gas

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<sup>44/</sup> Agoos, Alice and Peter Savage. U.S. Methanol Supplies Come Up Short. Chemical Week, Sept. 18, 1985. p. 38-39.

<sup>45/</sup> Economics Right for MTBE from Field Butanes. Oil and Gas Journal, May 27, 1985. p. 92-93.

oils. Other process routes to make MTBE include catalytic dehydrogenation of isobutane to yield isobutylene followed by etherification with methanol. In this route an isomerization plant would also likely be needed to convert normal butane into isobutane.

One simple and efficient technique for making MTBE in the refinery is the insertion of catalysts directly into the distillation fractionating column following the FCC units. <sup>46/</sup> The FCC output streams typically contain up to 20 percent isobutylene which can be processed directly to MTBE before separating the product stream. Further, by removing isobutylene from the isobutane-butylene stream going to the alkylation unit, a higher octane alkylate can also be obtained because, in effect, the isobutane to olefin ratio is increased at reduced butylene feed rate. <sup>47/</sup>

However, when MTBE facilities are added upstream of an alkylation plant, methanol and others must be removed from the alkylation feed since they cause increased acid consumption. With a stand-alone MTBE plant, only abbreviated purification facilities are needed since a high-purity product is not required.

Between 1980, the first year in which the U.S. International Trade Commission began reporting separate data on MTBE, and 1984, world production of MTBE has grown at an annual compound rate of 20 percent. As indicated in table 16, MTBE production capacity installed in the United States is around

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<sup>46/</sup> Savage, Peter. Catalytic Distillation with a Very Broad Reach. Chemical Week, Sept. 11, 1985. p. 32-33.

<sup>47/</sup> Pierce, V. E. and A. K. Logwinuk. Which Route to More Octane? p. 76.

TABLE 16. Major U.S. Producers of MTBE

| Company                     | Location              | Capacity (b/d) |
|-----------------------------|-----------------------|----------------|
| American Petrofina (Cosden) | Big Spring, Texas     | 600            |
| Amoco                       | Whiting, Indiana      | 2,500          |
| Amoco                       | Yorktown, Virginia    | 500            |
| Arco Chemical               | Channelview, Texas    | 4,600          |
| Champlin Petroleum          | Corpus Christi, Texas | 1,600          |
| Charter International Oil   | Houston, Texas        | 1,400          |
| Exxon Chemical              | Baytown, Texas        | 2,500          |
| GHR Refining*               | Good Hope, Louisiana  | 2,800          |
| Phillips                    | Sweeny, Texas         | 2,800          |
| Texaco                      | Port Neches, Texas    | 6,300          |
| Texas Petrochemical Company | Houston, Texas        | 6,500          |
| Texas Petrochemical Company | Baytown, Texas        | 600            |

\* Shut Down

SOURCE: Unzelman, G. H. Problems Hinder Full Use of Oxygenates in Fuel. Oil and Gas Journal, July 2, 1984. p. 59-65; Storck, William. MTBE Growth Limited Despite Lead Phasedown in Gasoline. Chemical and Engineering News, July 15, 1985. p. 12-13; Savage, Peter. Catalytic Distillation with a Very Broad Reach. Chemical Week, Sept. 11, 1985; and Obel, Michael. U.S. Refiners Press Work on Projects at 32 Sites. Oil and Gas Journal, Oct. 28, 1985. p. 50-51.

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32,700 b/d. Exxon also produces MTBE at its petrochemical plant in Baton Rouge, Louisiana, then decomposes it in a second column to regenerate purified isobutylene for making butyl rubber. A side stream of MTBE will be used for gasoline blending by the company. <sup>48/</sup> In addition, Sun Refining and Marketing Company recently announced that it will build a \$14 million MTBE plant at its Marcus Hook, Pennsylvania refinery to produce, 2,100 b/d of MTBE. <sup>49/</sup> Outside the United States, approximately 18,500 b/d of MTBE capacity is currently on stream in Europe. However little, if any, MTBE is imported to the United States from Europe.

One related alternative to MTBE is tert-amyl methyl ether (TAME). TAME has an octane number of 107 and has been tested as a gasoline additive by Gulf Canada. Like MTBE, TAME can also be made by combining extractive distillation and catalytic reaction in a single unit. Exxon has licensed, but not used, a process of this nature for making TAME.

#### 4. TBA

Tertiary butyl alcohol is the most commonly used cosolvent for methanol. Although other heavier alcohols and/or compatible oxygenates can exhibit cosolvent properties, TBA has the advantage of being available commercially and of having relatively high-octane quality. TBA has been blended in gasoline under the trade name of Arconol since 1969. As separate gasoline blending

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<sup>48/</sup> Savage, Peter. Catalytic Distillation with a Very Broad Reach. Chemical Week, Sept. 11, 1985. p. 32.

<sup>49/</sup> The Energy Daily, Dec. 12, 1985. p. 2.

agents, neither methanol nor TBA is completely satisfactory. However, mixtures of the two overcome most of their individual shortcomings, and are marketed by Arco under the trademark of Oxinol. Using TBA-methanol additives generally requires backing out some butane in order to stay within acceptable vapor pressure limits.

TBA can be produced by hydration of isobutylene with water similar to the catalytic addition of methanol to isobutylene for making MTBE. Currently the only plant in the United States producing TBA is Arco's plant at Bayport, Texas where the TBA is a coproduct from the manufacture of propylene oxide. The process utilizes peroxidation of propylene via isobutane yielding TBA. The current output is in the range of 20,000 to 25,000 b/d of TBA. The only other significant source of TBA for fuel use is in the Netherlands. There, Arco Chemi Company went on stream in 1982 with a TBA capacity of about 10,000 b/d, also in conjunction with propylene oxide production. While other alcohols have EPA's approval to be used as cosolvents for methanol, to date the alternatives are not as attractive from the standpoint of either octane number or economics, and supplies are limited.

#### E. SUMMARY AND CONCLUSIONS

As is evident from the foregoing, there are about as many combinations of process options for enhancing the octane rating of gasoline as there are refineries. In addition, scientists and engineers are seeking to develop new processes and improve older ones. New additives are also being tested. One

area in which the potential is still just beginning to be realized is in the development of new catalysts. Catalytic reactions have been part of refining operations for many years, but with newer pressures to process heavier crudes and extract higher octane components, refiners are looking for improved catalysts to play a major role.

The major changes affecting the refining industry as a result of the lead phasedown will be a slightly higher use of energy in the manufacture of gasoline and a shift in products streams. Higher energy use will tend to reduce the overall output of the refinery relative to the amount of crude entering it. But with current overcapacity, this is not likely to be a problem in terms of supply of products.

Higher energy use because of additional refinery processing will also contribute to a higher cost in producing gasoline. This cost will vary depending on the refinery processing involved, but is expected to be on the order of two cents per gallon. <sup>50/</sup> It would be against this cost of octane enhancement that the use of oxygenated additives would have to compete. However, the extent to which this cost will be noticeable to the consumer is largely dependent on the price of oil. With some crude oil prices dropping by nearly 50 percent in the first months of 1986, prices throughout the petroleum industry are likely to be affected, including the price of gasoline. This price drop, resulting from increased OPEC production, will be a benefit to refiners dependent on purchased crude. However, fully integrated firms, involved in oil production as well as refining, are finding their corporate revenues declining. The full impact of these supply adjustments has not yet been felt.

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<sup>50/</sup> The Energy Daily, Mar. 7, 1985. p. 1,4.

Another interesting aspect of the lead phasedown that affects prices is that the cost of making leaded gasoline at 89 octane using only 0.1 g/gal lead will likely become higher than the cost of making unleaded regular. This is because unleaded regular is currently marketed at 87 octane, whereas the octane value of the clear unleaded pool needed to make 0.1 g/gal leaded regular must be raised to 88.2 octane from the value of 83.6 it had when 1.1 g/gal lead was added.

In conclusion, the economics of octane enhancement, particularly with regard to the use of oxygenates, depend on many variables, most of which are site specific. These variables include:

- o The properties of the crude petroleum processed;
- o The market opportunities for the refiner's complete slate of products;
- o The response of the individual refinery's gasoline pool to a particular octane enhancer;
- o The cost or benefit of vapor adjustment that an octane enhancer may require;
- o The local availability of octane enhancers including the costs of delivery versus the costs of producing them;
- o Value to the refiner of public acceptance of oxygenates vis-a-vis auto maker's recommendations, etc.; and
- o State and Federal tax considerations.

The major physical considerations involve the two factors explained earlier: Reid vapor pressure (RVP) and blending octane value (BOV). Each of these factors must be considered when an octane enhancing component is added to the gasoline pool. Theoretically, this is done by balancing equations for vapor

pressure and octane value. The solutions of these equations generally determine the amount of butane that must be added or withdrawn to compensate for an amount of a given additive. These values can then be translated into cost comparisons into which other considerations become important, such as those mentioned above. If the range of options is to include constructing or modifying processing equipment, these costs would have to be considered and weighted by some amortization factor. Tax considerations regarding alcohol fuels, which are reviewed in the next chapter, are another important consideration.

All in all, one might summarize by saying that in response to the lead phasedown, the refining industry is in a state of flux. But, then, it always has been.

## III. ALCOHOL FUELS--BACKGROUND AND CURRENT STATUS\*

A. BACKGROUND AND HISTORY

Methanol and ethanol are two related compounds that are chemically classified as alcohols. The chemical formula for methanol is  $\text{CH}_3\text{OH}$ , and that for ethanol is  $\text{C}_2\text{H}_5\text{OH}$ . The popular terms for these two chemicals are "wood alcohol" for methanol and "grain alcohol" for ethanol. This terminology derives from the sources from which these compounds were originally made, although both can also be made from petrochemicals. The alcohol used in beverages is always ethanol, made from grain or other agricultural crops.

Ethanol has been distilled from agricultural crops for thousands of years, primarily for use in beverages. Grain-derived alcohol for other than beverage use has been of interest in the United States at various times during the 20th century. <sup>51/</sup> In the first decade of the century, denatured grain alcohol was made tax exempt in order to encourage its use for fuel and industrial purposes. During the Great Depression of the 1930s, alcohol fuels were promoted primarily as a farm relief measure. Some alcohol was produced and used as an automotive fuel at this time in the midwestern grain belt, but alcohol so produced could not compete economically with gasoline from petroleum. During World War II, interest in agriculturally derived ethanol peaked once again, when the Federal

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\* By Migdon R. Segal, Analyst in Energy Technology, Science Policy Research Division.

<sup>51/</sup> U.S. Library of Congress. Congressional Research Service. The Alcohol Fuels: A Study of Technical and Supply Factors. Report No. 80-123 SPR, by Migdon R. Segal et al. Washington, 1980.

Government built distilleries to produce ethanol used in the manufacture of synthetic rubber. The possibility of using grain alcohol as an automotive fuel was revived periodically during the 1950s and 1960s, when the intent was to dispose of enormous grain surpluses by converting the grain to fuel alcohol. However, the idea never progressed beyond the discussion stage, as once again ethanol could not compete economically with gasoline.

Alcohol fuels were also of interest in nations other than the United States, especially during the 1920s and 1930s. During that time, 32 countries had either compulsory or voluntary alcohol fuel programs, including nearly every Western European nation. <sup>52/</sup> Again, during World War II, many countries turned to alcohol and other substances as automotive fuels, when the disruption caused by the war led to the development of substitutes for gasoline. Germany, which was particularly in need of fuel for its war machine, developed an entire industry for producing gasoline from coal.

There is no major history of methanol being used as an automotive fuel. Wood was used as a source of fuel for autos in some countries during World War II, but the wood was burned directly and not converted to methanol.

The energy crises of the 1970s revived interest in alcohol fuels for automobiles in the United States. Spurred by favorable legislation enacted both nationally and in various States, ethanol from grain began to be used as an auto fuel, mixed with gasoline in a blend of 10 percent ethanol and 90 percent gasoline popularly known as "gasohol". During the 1980s, this blend gained a foothold and became an important component of the Nation's automotive fuel.

Also in response to the energy crises of the 1970s the nation of Brazil adopted a policy of replacing imported gasoline with alcohol produced from

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<sup>52/</sup> Ibid., p. 7.

sugar cane grown in that country. Brazil's alcohol fuels program has been highly successful. Automobiles operating there today run on either a blend of 22 percent alcohol and 78 percent gasoline or on pure alcohol. Nearly all new cars produced in Brazil are now designed to run on pure alcohol. The alcohol fuels industry in Brazil can readily produce alcohol for export, and Brazilian alcohol has recently become a major, and controversial, presence in the U.S. alcohol fuels market. <sup>53/</sup>

Methanol has been slower to develop as an automotive fuel than ethanol. It can not be made readily from agricultural crops, it is a less powerful fuel than ethanol in terms of energy per gallon, and it is less compatible with existing automobiles than is ethanol. However, economic and supply factors may outweigh these problems and make methanol the alternative fuel of choice in the future. Methanol may be obtained from coal, which the United States possesses in great quantity, and from wood which also can supply a large volume on a continual basis. In addition, methanol is currently produced from natural gas. The cost for methanol from coal is projected to be less than that of ethanol.

The following sections outline the legislation now in effect governing alcohol fuels in the United States and its significance to the growth of the alcohol fuels industry. They also discuss major pending legislation, and summarize the present status of domestic ethanol, Brazilian ethanol, and methanol as of early 1986.

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<sup>53/</sup> U.S. Library of Congress. Congressional Research Service. Gasohol: The Alcohol Fuels. Issue Brief No. IB74087, by Migdon Segal. (Continuously updated.)

B. THE EFFECTS OF FEDERAL AND STATE LEGISLATION ON THE  
DEVELOPMENT OF AN ALCOHOL FUELS INDUSTRY

1. Federal Legislation Through the 98th Congress

Beginning with the Energy Tax Act of 1978, alcohol fuels became the subject of much legislation, most of it intended to promote the use of this alternative fuel. This section describes those measures that had a significant impact on the development of the alcohol fuels industry, and summarizes their effects, without attempting to include all bills in which alcohol fuel is mentioned.

a. Energy Tax Act

The Energy Tax Act of 1978 (P.L. 95-618) exempted fuels containing ten percent or more of alcohol from the Federal highway excise tax on gasoline, which was then four cents per gallon. (Funds from this tax go to the Highway Trust Fund.) The exemption was to last until 1984. To qualify for this exemption, the alcohol could be either ethanol or methanol produced from renewable sources, i.e., it could not be obtained from petroleum, natural gas, or coal.

This legislation is considered to have stimulated the growth of a substantial alcohol fuels industry in the United States. The tax advantage from this law was quite valuable to the seller of alcohol for use as a fuel, since his gallon of alcohol could be used to make 10 gallons of "gasohol." Thus 40 cents of tax was avoided for each gallon of alcohol sold for this purpose. Following enactment of P.L. 95-618 in November 1978, the gasohol blend began to appear on the market during 1979 and 1980, starting in Farm Belt States that were actively

promoting its use, such as Nebraska and Iowa. Sales of alcohol for fuel reached roughly 40 million gallons in 1979 and 80 million gallons in 1980. 54/

b. National Alcohol Fuels Commission

In an amendment to the Surface Transportation Assistance Act of 1978 (P.L. 95-599), a National Alcohol Fuels Commission was created, with a mandate to conduct a one-year study of alcohol's potential as a fuel. The Commission began its activities in the summer of 1979. It consisted of 19 members from both the public and private sectors, with Senator Birch Bayh (D-Ind.) as chairman and Representative Robert A. Roe (D-N.J.) as vice chairman. The Commission subsequently received a six-month extension beyond its original charter, and released its final report, entitled "Fuel Alcohol: An Energy Alternative for the 1980s" in February 1981. 55/

The Commission's recommendations for an expansive alcohol fuels program heavily supported by the Federal Government were not acted upon, as they were diametrically opposed to the incoming Reagan Administration's plan for ending Federal involvement in alcohol fuels development and commercialization. Nevertheless, the Commission, in its hearings and publications, probably increased public acceptance of alcohol fuels and thus contributed to the growth of the industry.

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54/ Potter, Fred. Telephone conversation. Information Resources, Inc., Nov. 1985.

55/ U.S. National Alcohol Fuels Commission. Fuel Alcohol: An Energy Alternative for the 1980s. Final Report. Washington, 1981.

c. Windfall Profit Tax Act

The Crude Oil Windfall Profit Tax Act of 1980 (P.L. 96-223) was enacted in April 1980. The Act postponed the expiration date of the Energy Tax Act highway excise tax exemption from 1984 to 1992. It also included income tax credits for blenders of alcohol-gasoline blends, tax credits for users of "straight" (pure) alcohol fuel, authority for the Bureau of Alcohol, Tobacco and Firearms (BATF) of the Treasury Department to simplify its regulations for alcohol fuel producers, and a Federal study of alcohol fuel imports, among other provisions.

The extension of the excise tax exemption stimulated the further expansion of the alcohol fuels industry by assuring producers that their tax break was good through 1992. Given this assurance, alcohol fuel sales jumped from 85 million gallons in 1981 to 234 million in 1982 and 443 million in 1983. <sup>56/</sup> Other provisions proved less useful: the blender tax credit has rarely been used, straight alcohol as a fuel remains undeveloped in the United States, and the simplified BATF regulations did not lead to the spread of small-scale alcohol "still" that some had envisioned. The study of imports recommended against a tariff, but this recommendation was not acted on by the Congress (see below).

d. Energy Security Act

The Energy Security Act (P.L. 96-294), included probably the most extensive program of U.S. Government support for alcohol fuels development ever

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<sup>56/</sup> Information Resources, Inc., Press release. Nov. 21, 1985.

enacted into law. The centerpiece of this legislation was a program of financial assistance totalling \$1.27 billion, to be available for loan guarantees, price guarantees, and purchase agreements. These funds were divided three ways: \$525 million to the Department of Agriculture to assist facilities producing less than 15 million gallons per year; \$525 million to the Department of Energy (DOE), for facilities producing more than 15 gallons per year; and \$220 million to DOE for a municipal waste to energy program.

In addition to the financial assistance program, the Energy Security Act (1) established an Office of Alcohol Fuels as an independent office within DOE; (2) set national production goals for alcohol fuels of 60,000 barrels per day (920 million gallons per year) by the end of 1982 and ten percent of U.S. gasoline consumption (roughly ten billion gallons) by 1990; (3) established a Department of Agriculture program of research, development, and technical assistance for producing alcohol fuels and biomass energy from various agricultural and forestry feedstocks; and (4) directed that Federal agencies increase the use of gasoline in Federal vehicles.

Of the original \$1.27 billion financial assistance program only three loan guarantees, totalling \$300 million, have been awarded, with another three still under negotiation, all from DOE's portion of the original program (see below). Little remains from the non-financial provisions: the Office of Alcohol Fuels within DOE still exists, but is much reduced in staff. The production goal of 920 million gallons per year by 1982 has not been met, although alcohol fuel sales have been climbing steadily and reached 444 million gallons in 1984, with 780 million gallons estimated for 1985. (See table 17 for a summary of annual sales figures.) The Agriculture Department research

program, dealing mostly with fermentation technology, has been funded at roughly three to four million dollars per year in recent years. The directive that gasohol be used in Federal vehicles is virtually a dead letter.

TABLE 17. U.S. Ethanol Sales for Fuel Use, 1979-1985\*  
(Source: Information Resources, Inc.)

| <u>Year</u> | <u>Ethanol Fuel Sales in Million Gallons</u> |
|-------------|----------------------------------------------|
| 1979        | 40                                           |
| 1980        | 80                                           |
| 1981        | 85                                           |
| 1982        | 234                                          |
| 1983        | 443                                          |
| 1984        | 567                                          |
| 1985 (est.) | 780                                          |

\* Includes Imports

Note: Virtually all of this ethanol has been used in the 10 percent "gasohol" blend. Total blend sales per year, therefore, can be obtained by multiplying these figures by ten.

e. Import Duties on Alcohol Fuels

In 1980, imports of alcohol fuels from Brazil began to be felt in the U.S. alcohol fuel market. Brazilian imports peaked at 7.7 million gallons in the month of April 1980. Concern over these imports led both the Congress (in the Windfall Profit Tax Act) and the National Alcohol Fuels Commission to request that the Treasury Department report on these imports and on possible measures to combat them, such as import duties. The Treasury Department report, issued in October 1980, recommended that no such action be taken.

Treasury's rationale was that imports had declined from their earlier peak, the imports had not harmed the domestic industry and in fact might be helpful (in building an alcohol fuels market and distribution network), and a tariff would violate the General Agreement on Tariffs and Trade (GATT).

The Congress disregarded this recommendation and established a tariff on alcohol fuel imports as part of the budget reconciliation bill enacted in December 1980 (P.L. 96-499). The congressional consensus appeared to be that the United States should not subsidize the importing of an energy source from another nation, by allowing the Brazilian alcohol to benefit from the excise tax exemption. The tariff was established at 10 cents per gallon in 1981, 20 cents in 1982, and 40 cents thereafter. (A 40 cent tariff on alcohol nullified the effect of the four cent per gallon exemption for gasohol.) The tariff was later raised to 50 and then to 60 cents per gallon, keeping pace with increases in the excise tax exemption.

#### f. DOE Appropriations

The Department of Energy has operated a small scale program of alcohol fuels research and development since the late 1970s. Funding for this program peaked at \$22 million for fiscal year 1980. The program was then cut back to \$18 million in fiscal year 1981, and to \$10 million in FY 1982. The proposed budget for this program for FY 1983 would have cut the program to \$3 million, and would have ended the program by having the funding "zeroed out" in subsequent years. Congress did not accept this proposal, and kept the funding level at \$10 million. For FY 1984 and succeeding years, alcohol fuels has not been listed as a separate line item, instead coming under the general biomass energy program. DOE estimates that funding levels for work under

the Biomass program related to alcohol fuels have declined from \$7.2 million in FY 1984 to \$4.1 million in FY 1985, and (estimated) \$4 million for FY 1986.

g. 1981 Budget Rescission

The Reagan Administration, upon taking office, announced its intention to virtually terminate the entire Energy Security Act program as "part of the general effort to adopt market principles to achieve national energy goals." In early 1981, the Administration proposed the rescission of the authority for alcohol fuels loan guarantees under the Energy Security Act. Congress responded by rescinding nearly all of the funds for two of the three programs authorized by the Energy Security Act; one of these programs would have been operated by the Department of Agriculture and would have aided small-scale alcohol fuels operations and the second would have been sponsored by the Department of Energy and would have financed an energy from solid wastes program. These rescissions were made as part of P.L. 97-12, enacted in 1981. The third of these programs would have provided \$525 million to DOE for assisting large alcohol fuels plants. Of this funding, \$250.6 million was rescinded by P.L. 97-12, and an additional \$40 million was transferred out of the program under P.L. 97-394, enacted in 1982. The remaining \$234 million was retained in the reserve fund.

Subsequently these funds were used to award loan guarantees to eleven companies for projects that would be capable of producing 365 million gallons of alcohol annually, with the total in loan guarantee funding for these projects at \$635 million. (More funding could be awarded than the total in the fund, because the Department of Energy was allowed to "leverage" the funding to three times the authorized total). The program ran into difficulties, however, as most of the proposed projects could not assemble the necessary private financing, even with the Federal loan guarantee. Three grants have been issued: in October

1982, \$140.9 million to the New Energy Company of Indiana for a 50 million gallon/year ethanol plant in South Bend, Indiana; in October 1984, \$72 million to the Tennol Corporation for a 25 million gallon/year plant in Jasper, Tennessee; and in September 1985, \$87.7 million to the Agrifuels Refining Corporation for a 35 gallon per year plant in New Iberia, Louisiana. 57/ Three additional grants are still in negotiation, but since DOE's authority to issue these grants had expired, additional legislation was necessary if these grants were to be issued. Legislation extending the grant authority was enacted in December 1985 (see below).

#### h. Tax Exemption Increase to 5 Cents

In December 1982, in an amendment to the Surface Transportation Assistance Act of 1982 (P.L. 97-424), the highway excise tax exemption for alcohol fuels was raised from 4 to 5 cents per gallon. (Under this legislation the tax itself was increased from 4 to 9 cents per gallon of gasoline.) The amendment correspondingly raised the tariff on imported alcohol from 40 to 50 cents per gallon, and also provided an exemption from the full 9 cents for "straight" alcohol (with 85 percent or more of alcohol).

The Reagan Administration did not oppose the increased exemption, although earlier in 1982 it had suggested that the four-cent exemption be removed. Removal of the exemption never became a formal Administration proposal, and the idea was quietly dropped after strong congressional opposition developed.

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57/ Beckman, Dan. Telephone conversation. Office of Alcohol Fuels, U.S. Dept. of Energy. Nov. 1985.

i. Tax Exemption Increase to 6 Cents

The highway tax exemption was raised to 6 cents per gallon in an amendment to P.L. 98-369, the Deficit Reduction Act of 1984. This measure, enacted in July 1984, also raised the tariff to 60 cents per gallon, once again keeping pace with the tax increase. It also decreased the tax on "straight" methanol fuel derived from natural gas from 9 to 4.5 cents per gallon (the earlier exemption had specified alcohol from biomass and had not included alcohol from natural gas).

j. Use of Surplus Grain for Alcohol Fuel

In 1982, legislation was introduced and passed (P.L. 97-358) that was intended to encourage the use of surplus grain stocks held by the Department of Agriculture to make alcohol for fuel. The bill would have expanded a small Agriculture Department pilot program to devote as much as 100 million bushels of U.S.-owned surplus corn to alcohol production. The alcohol produced was to be disposed of in one of three ways: used by Federal agencies, stored by the Federal Government, or sold in the commercial market in a manner that would not disrupt that market (i.e., lower the price). Had this program gone into effect, most of the alcohol produced would likely have been stored. Only limited amounts could be used in the Federal transportation fleet, and sales in the commercial market would be highly limited by the requirement not to disrupt that market.

The program authorized by P.L. 97-358 was not implemented, because the "payment-in-kind" program adopted by the Administration proved to be highly effective in reducing agricultural surpluses. The storage of large quantities of alcohol might have been the beginning of a "strategic alcohol reserve," a

concept which is still envisioned by alcohol fuel advocates as paralleling the Strategic Petroleum Reserve. The strategic alcohol reserve concept is now embodied in legislation under consideration by the 99th Congress (see below).

#### k. Methanol Vehicle Program

In October 1986, the Congress approved funding for a methanol vehicle program to be operated by the Department of Energy (DOE) and the Department of Defense (DOD). The funding was provided in an amendment to the continuing appropriations resolution enacted in October 1986 (P.L. 98-473). It allocated \$1.3 million to DOD and \$1 million to DOE to provide for methanol car fleets, to be purchased from auto manufacturers. As many as 1200 vehicles operating on pure methanol could be provided under this program.

As of mid-1987, the DOD test program was progressing as planned, with vehicles operating on methanol being tested. The DOE test was lagging behind schedule because of difficulties in finding test locations. <sup>58/</sup>

#### 2. State Laws Encouraging Alcohol Fuel Use

Many States have tax incentives to encourage the sale of alcohol fuels. Figure 3, provided by Information Resources, Inc., shows the tax incentives existing as of December 1985. (The numbers shown on the map represent the tax incentives for that particular State in cents per gallon of gasoline, except where otherwise specified.)

These State tax incentives, added to the Federal incentive, have made alcohol-gasoline blends competitive with gasoline in many States, particularly in

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<sup>58/</sup> DOE Neat Methanol Fleet Said Facing Problems, Hill Aid Sought. Alcohol Week. June 10, 1987. p. 1.

# U.S. STATE TAX INCENTIVES

DECEMBER 1, 1985



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the Midwest and South. Table 18 lists the ten States with the highest total sales of ethanol-gasoline blend through the third quarter of 1985:

TABLE 18. Ten Leading States with Alcohol-Gasoline Blend Sales, Jan.-Sept. 1985 (figures in million gallons of blend)

|             |       |              |       |
|-------------|-------|--------------|-------|
| 1. Illinois | 725.7 | 6. Michigan  | 373.8 |
| 2. Ohio     | 488.6 | 7. Iowa      | 341.7 |
| 3. Indiana  | 458.6 | 8. Texas     | 311.9 |
| 4. Florida  | 451.6 | 9. Kansas    | 221.8 |
| 5. Kentucky | 401.6 | 10. Virginia | 221.1 |

(Source: Information Resources, Inc.)

In terms of percent of the market, table 19 lists the ten leading States for July-September 1985:

TABLE 19. Ten Leading States with Percent of Market Share for Alcohol-Gasoline Blend, July-September 1985 (figures in percent share of market)

|             |       |                 |       |
|-------------|-------|-----------------|-------|
| 1. Iowa     | 34.42 | 6. Illinois     | 20.12 |
| 2. Nebraska | 32.2  | 7. Colorado     | 17.3  |
| 3. Kentucky | 30.0  | 8. South Dakota | 14.5  |
| 4. Kansas   | 24.2  | 9. Ohio         | 14.3  |
| 5. Indiana  | 24.1  | 10. New Mexico  | 13.6  |

(Source: Information Resources, Inc.)

The State tax laws, and the sales figures for the ethanol blend, have shifted rapidly over time; for instance, California had been one of the leading States until its tax break was cancelled. While the various State figures have shifted, the Midwest has always predominated in alcohol blend sales. Presumably this is because the raw material from which alcohol is made in the United States is corn, grown mostly in the Midwest. Figure 4 shows the geographic distribution of the leading alcohol fuels States.

### 3. Legislative Activity in the 99th Congress Relating to Alcohol Fuels

The first session of the 99th Congress, which adjourned in December 1985, addressed five legislative issues related to alcohol fuels: (1) the excise tax

exemption; (2) alcohol fuel imports; (3) action to promote methanol as an auto fuel; (4) the proposed strategic ethanol reserves; and (5) extension of the DOE loan guarantee program. <sup>59/</sup>

a. Excise Tax Exemption

The future of the excise tax exemption for alcohol-gasoline blends was considered as part of the tax reform legislation passed by the House in December 1985 (H.R. 3038). The Administration's tax reform proposal would have eliminated the 6 cents per gallon excise tax exemption, and would also have eliminated the 60 cents per gallon tariff on alcohol fuel imports. It would have kept the 60 cents per gallon blenders' tax credit, which has existed since the Windfall Profit Tax Act was enacted but has rarely been used. (The blenders' tax credit is considered to be important for the future if the Du Pont methanol-ethanol-gasoline blend is to become an important new automotive fuel. As discussed in chapter 2, this blend may solve some of the problems of bringing methanol into the fuel network, but it has not been used thus far because of EPA rulings limiting allowable vapor pressures.) <sup>60/</sup> Alcohol fuels supporters claim the highway excise tax exemption is absolutely essential for the future of their industry, and that eliminating it would be breaking faith with those who had invested in alcohol fuel plants on the assumption that the 1992 date would hold.

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<sup>59/</sup> Segal, Nigdon. *Gasohol, the Alcohol Fuels*, op. cit.

<sup>60/</sup> Lorgan Sees No Future for 60 Cent Blenders Credit in Tax Bill. *Alcohol Week*. Nov. 18, 1985. p. 2.

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The Administration's proposal to strike the tax exemption was part of the attack on exemptions and "loopholes" featured by the overall tax reform proposal. A further reason for opposing the exemption is the concern by highway officials that the exemption is reducing highway revenues. The Highway Users Federation estimates that in 1985, Federal revenues were reduced by \$388 million and State revenues by \$173 million, for a total of \$561 million in reduced highway revenues due to the gasoline exemptions. 61/

The tax reform bill, reported by the Ways and Means Committee in December 1985, and then passed by the House, retained the six-cent tax exemption and the corresponding tariff, but eliminated the blenders' tax credit, thus reversing the Administration proposal on both issues. With this action it is likely that the tax exemption will be retained, since the Senate historically has supported it more strongly than the House.

#### h. Alcohol Fuel Imports

Imports of alcohol from Brazil, and the possibility of imports from the Caribbean nations, attracted legislative attention during 1985. Imports of a blend containing 93 percent ethanol to 7 percent toluene began arriving in the United States from Brazil, following a U.S. Customs Service ruling that such blends could be imported without being subject to the 60-cent tariff. The Customs Service later reversed its original ruling, making the blend subject to the tariff. However, it "grandfathered" six U.S. importers, who claimed that they had entered into contracts based on the original ruling, and gave

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61/ Highway Users Federation Highway Fact Book, 1986. Washington, 1985. p. 9.

them until November 1, 1985, to import the blend duty-free. This led to rumors that vast quantities of ethanol-toluene blend were about to flow through this loophole. 62/ Legislation was therefore introduced that would require a 60 cents per gallon duty on any ethanol imported for fuel use, whether blended with other substances or not. (S. 575, by Senator Dole; H.R. 1566, by Representative Leach; H.R. 1720, by Representative Durbin.) This legislation was added as an amendment to the Senate version of the appropriations bill containing funding for the Treasury Department (which includes the Customs Service) for fiscal year 1986. However, the amendment was dropped from the bill in conference, since by the time the conferees met in October 1985, it had become obvious that only small amounts of the blend would arrive in the United States before the November 1 deadline set by Customs.

The Caribbean Basin Initiative (CBI) was enacted in 1983 with the purpose of encouraging 28 small countries in Central America and the Caribbean area to develop their economies through U.S. economic aid and trade initiatives. The CBI program includes duty-free access to the U.S. market for exports from those nations that were produced or "substantially transformed" there.

Acting under this program, some corporations announced plans to build facilities in CBI nations which would "upgrade" Brazilian ethanol by decreasing its water content. (Ethanol intended for use in a blended fuel with gasoline must be virtually free from water in order to prevent phase separation from taking place in the blend.) U.S. ethanol producers claimed that these firms were unfairly taking advantage of the CBI, since the ethanol would not be produced in the CBI area but merely dried there. The Customs Service ruled that the drying process qualifies as a "substantial transformation," and thus ethanol dried in

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62/ Customs Ethanol-toluene 'Grandfather' Ruling Starts Contract Stampede. Alcohol Week. Aug. 26, 1985. p. 1.

the CBI region may be brought into the United States duty-free. Legislation has been introduced to reverse this ruling. (S. 576, by Senator Dole; H.R. 1567, by Representative Leach; H.R. 1720, by Representative Darbin.)

The farm bill enacted in 1985 (P.L. 99-198) included an amendment by Representative Bercuter (R-Neb), asking that the Department of Agriculture study the impact Brazilian ethanol imports have on domestic grain prices and on the ethanol refining industry. The amendment also provides that the Agriculture Department, in consultation with the International Tariff Commission and the United States Trade Representative, is to "determine what relief should be granted because of the interference of subsidized Brazilian ethanol with the domestic ethanol industry."

c. Methanol Legislation

Legislation was introduced in both Houses of the 99th Congress which was intended to encourage the use of methanol as an automobile fuel by amending the way that corporate average fuel economy (CAFE) requirements are calculated for fuels with methanol. (S. 1097, introduced by Senator Danforth; H.R. 2955, introduced by Representative Wise.) Under this legislation, auto manufacturers would be required to count only the gasoline portion of a methanol-gasoline blend in calculating miles per gallon. Thus, a vehicle using 85 percent methanol and 15 percent gasoline, which traveled 24 miles to the gallon of blend, would be credited with traveling 160 miles per gallon of gasoline. (Methanol-powered vehicles are expected to use 15 percent gasoline with the methanol.)

The Senate bill, S. 1097, was reported by the Senate Committee on Commerce, Science, and Transportation in August 1985 (S. Report 99-128) after

being modified to extend its provisions to ethanol as well as methanol, per an amendment sponsored by Senators Long and Exon. 63/

A more comprehensive methanol bill was introduced in the House in September 1985 by Representatives Sharp, Broyhill, and others. The bill is H.R. 3355, the "Methanol Energy Policy Act of 1985." H.R. 3355 includes: (1) a demonstration program with 5000 methanol cars per year purchased by the Federal Government annually, beginning with FY 1987; (2) methanol truck and bus demonstration programs; (3) a requirement that, if the bus demonstration program results are satisfactory, all buses purchased with Federal funds in high-pollution areas after 1991 be methanol-powered; (4) an interagency commission to be established to coordinate Federal methanol programs; (5) a requirement that all vehicles purchased by the Federal Government be guaranteed by the manufacturer as suitable for operation on all EPA-approved fuels; and (6) CAFE provisions similar to those in the Danforth bill (but applicable only to methanol, not ethanol).

#### d. Strategic Ethanol Reserve

Legislation that would require the formation of a "strategic ethanol reserve" (SER) was introduced by Representatives Leach and Durbin (H.R. 3299). In October 1985, this legislation was adopted by voice vote as an amendment to H.R. 2100, the farm bill. The amendment would set a goal of an ethanol reserve one-tenth the size of the strategic petroleum reserve (SPR). The SPR now contains 500 million barrels, or 21 billion gallons, of oil, thus the SER would ultimately contain over 2 billion gallons of ethanol. This total would be

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63/ U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Methanol and Ethanol Vehicle Incentives Act of 1985. House Report No. 99-128, 99th Cong., 1st Sess. Washington, U.S. Govt. Print. Off.

reached by obtaining 125 million gallons of ethanol in fiscal 1986, 252 million gallons in fiscal 1987, 378 million gallons in fiscal 1988, and 420 million gallons annually after that until the goal was met. For fiscal year 1986, the ethanol would be obtained by exchanging corn for ethanol under a payment in kind (PIK) plan by which ethanol producers would be offered an equivalent amount (in dollar value) of corn for their ethanol.

The SER amendment was dropped from the farm bill by the conference committee considering that bill in December 1985. Instead, the committee included a study to be performed by the Department of Agriculture on the feasibility of an SER, to be completed within one year. If the results of the study are positive, Agriculture is then authorized to establish an SER.

e. DOE Loan Guarantee Program

As stated above, the loan guarantee program for alcohol fuels plants created by the Energy Security Act of 1980 was reduced in scope by budget rescission legislation in 1981. By the end of fiscal year 1985 three grants had been issued and three additional grants were still in negotiation. The proposed grants would go to Circle Energies Corporation, for a 15 million gallon per year plant in Blair, Nebraska; to Minnesota Alcohol Producers, for a 15 million gallon per year plant in Mankato, Minnesota; and to New England Ethanol Producers, for a 25 million gallon per year plant in Auburn, Maine. With the end of fiscal year 1985, DOE's authority to grant these loan guarantees expired.

Legislation extending DOE's authority to issue these three loan guarantees was added by the Senate as an amendment to three separate bills: the Department of Agriculture appropriations bill (H.R. 3037) in October 1985; the budget

reconciliation bill (S. 1730) in November 1985; and the continuing resolution (H.J. Res. 465) in December 1985. The amendments on the three bills were identical; they extended DOE's authority to issue these loan guarantees for an additional nine months, to June 30, 1986, and allowed DOE to modify the terms of these guarantees if necessary. In all three cases the amendment was accepted by voice vote in the Senate and sent to conference with a House bill not containing this provision. While failing in its first two attempts to extend DOE's loan guarantee authority, the Senate prevailed on the third try when the continuing resolution was enacted.

An additional congressional action relating to the loan guarantee program took place in December 1985, when the Senate further amended the continuing resolution to allow the New Energy Co. of Indiana (NECI) plant built under this program in South Bend, Indiana to receive a further loan of \$3 million for an odor control system. The facility was reportedly producing an offensive odor which had led to lawsuits and the threat of action against the plant by city and State governmental bodies. This provision also was included in the continuing resolution and thus enacted into law.

In early 1986 the NECI plant was reportedly near bankruptcy. A bankruptcy would mean that NECI would default on its loan, and DOE would take control of the plant. 64/

#### C. ALCOHOL FUELS TODAY

The total consumption of alcohol fuel in the United States for the calendar years 1984, 1985 (estimated), and 1986 (projected), for each of the three major supply sources for alcohol fuel, i.e., domestic ethanol, imported ethanol, and

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64/ Loss of \$8-million State Subsidy Seen Forcing New Energy into Bankruptcy. Alcohol Week. Feb. 17, 1986. p. 1.

methanol, are summarized in table 20. The 1985 total is about one percent of U.S. gasoline consumption.

TABLE 20. U.S. Alcohol Fuel Consumption, 1984-1986  
(Figures in millions of gallons)

|                             | <u>1984</u> | <u>1985 (est.)</u> | <u>1986 (proj.)</u> |
|-----------------------------|-------------|--------------------|---------------------|
| Ethanol (domestic)          | 444         | 650                | 725                 |
| Ethanol (imported)          | 123         | 130                | 100                 |
| Methanol (from natural gas) | 248.5       | 265                | 310                 |
| Total                       | 815.5       | 1045               | 1135                |

SOURCE: Information Resources, Inc.

The present status and outlook for each of these supply sources are summarized in the following sections.

#### 1. Domestic Ethanol

Figures 5-7 summarize the recent history of domestic ethanol production, the amount of grain used in that production, and the feedstock used.

The major producers of ethanol in the United States are shown in table 13, p. 47. Archer Daniels Midland (ADM) is unquestionably the giant of the industry, with more capacity than the combined total of the others shown in the table. According to the Washington Post, ADM accounts for 60 percent of the Nation's alcohol fuel production, with \$425 million in alcohol fuel sales in 1985. <sup>65/</sup>

To sum up, the domestic ethanol industry has developed rapidly, from zero to its current level in under a decade. Its legislative outlook remains strong; the 1985 congressional session ended with the excise tax exemption apparently preserved, and possibilities for congressionally imposed curbs on imports looking

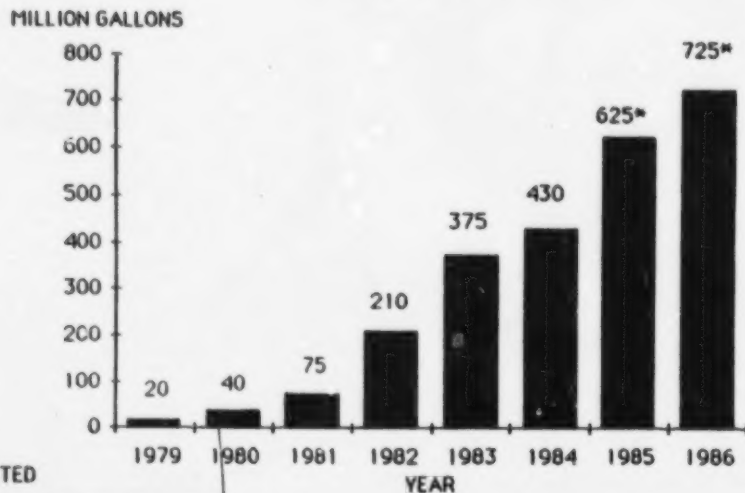
<sup>65/</sup> Ethanol Industry Booms Amid New Controversy. Washington Post. Dec. 8, 1985. p. H-1.

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# U.S. FUEL ETHANOL PRODUCTION 1979 - 1986



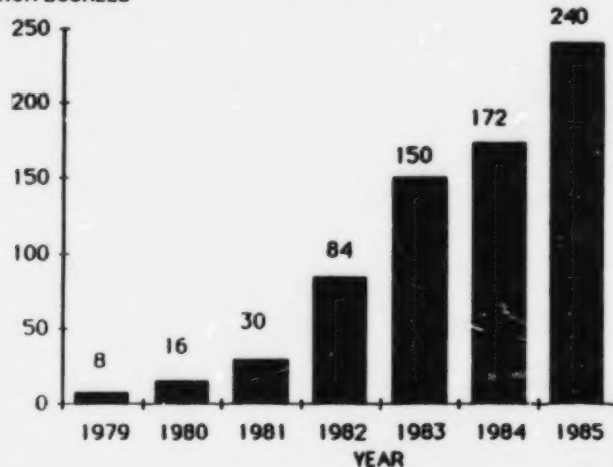
\* PROJECTED

SOURCE: INFORMATION RESOURCES  
INCORPORATED, WASH. D.C.

FIGURE 5

U.S. FUEL ETHANOL PRODUCTION  
UTILIZATION OF GRAIN  
1979 - 1985

MILLION BUSHELS



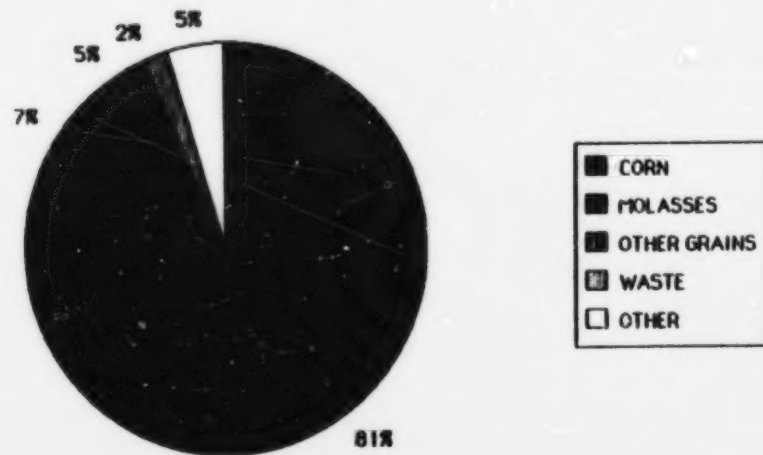
\* PROJECTED

SOURCE: INFORMATION RESOURCES  
INCORPORATED, WASH. D.C.

FIGURE 6

CMS-92

# 1985 ETHANOL PRODUCTION CAPACITY FEEDSTOCK UTILIZATION\*



\* PLANTS OVER 500,000 GPY AND CURRENTLY PRODUCING

SOURCE: INFORMATION RESOURCES INCORPORATED, WASH., D.C.

FIGURE 7

CBS-93

promising. However, the ethanol industry is currently suffering from the effects of falling oil prices. Up to now ethanol has been used, and priced, as a substitute for gasoline, therefore its market price falls as the price of gasoline falls. Some ethanol advocates believe that with the lead phase-down, ethanol will come to be seen as an octane booster, thus its price would not depend on the price of gasoline but on the price of competitive octane boosting methods. One estimate is that octane boosting at the refinery would cost 2 cents per gallon to the refiners. If this estimate is correct, this would translate to a 20 cent per gallon advantage to the marketer of alcohol fuels used in the 10 percent gasohol blend. This advantage would be added to the 60 cent advantage from the excise tax exemption, and to the additional advantage from State tax exemptions where they exist. However, the ethanol industry must prepare for the possible loss of those tax exemptions. The Federal exemption expires in 1992. Further extension beyond that date of a tax advantage first granted in 1978 and intended to be a temporary provision to aid the startup of a new industry might be difficult, particularly in the light of growing objections to the loss of revenues to the Highway Trust Fund caused by this exemption. Similar considerations apply in the States, and some State tax exemptions have already been repealed. Thus the use of alcohol fuel for its octane boosting properties could be seen by the alcohol fuels industry as partially making up for the prospective loss of Federal and State tax advantages.

## 2. Imported Ethanol

The estimate for alcohol import sales (given above) shows a decline from 123 million gallons in 1984 to 100 million gallons in 1986. This estimate

is speculative, since the future of alcohol imports in the U.S. alcohol fuels market depends more on governmental decisions than on market factors. Imports from Brazil were the subject of an action filed by domestic ethanol producers in February 1985 with the International Trade Administration (ITA) of the U.S. Department of Commerce, and with the U.S. International Trade Commission (ITC). In these "antidumping and countervailing duty petitions," the U.S. producers claim that the Brazilian government unfairly subsidizes its ethanol industry, thus allowing Brazil to sell ethanol in the United States at prices that undercut U.S. prices. Brazil has denied these charges. The case had proceeded through various preliminary steps, with some indications that the Brazilian and U.S. governmental authorities involved were trying to reach an "out of court" settlement fair to both countries. <sup>66/</sup> In March 1986, the ITC found that Brazilian ethanol had not materially injured the U.S. industry, thus ending the case; however, the domestic producers were considering an appeal. <sup>67/</sup>

While virtually all imports of alcohol fuel into the United States thus far have come from Brazil, the Caribbean Basin countries could become alcohol fuel exporters in the future, particularly since imports of alcohol fuel produced in those nations is not subject to tariff under the CBI legislation. The question of CBI coverage for Brazilian alcohol dried in CBI nations is still open, and may be resolved by legislation barring such coverage. This would remove the immediate threat to U.S. producer interests from the CBI countries. However, given time, it appears likely that some of those nations will develop their own facilities for converting CBI-grown sugar cane to ethanol, which would

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<sup>66/</sup> U.S.-Brazil Ethanol Deal Could End Tariff, Let U.S. Producers Market Imports. Alcohol Week. Nov. 11, 1985. p. 1.

<sup>67/</sup> ITC Finds No Material Injury to U.S. Ethanol Industry, Brings Case to Halt. Alcohol Week. Mar. 10, 1986. p. 1.

unquestionably qualify for favorable tariff treatment under the current CBI legislation. <sup>68/</sup>

These questions concerning alcohol imports are the subject of legislative interest in the 99th Congress, as mentioned previously. However, legislation satisfying U.S. producer interests might harm U.S. relations with Brazil and with the CBI nations.

### 3. Methanol

Methanol is presently made from natural gas. The IRI estimate shows methanol use as a fuel rising gradually from 248.5 million gallons in 1984 to 310 million gallons in 1986. Much of this capacity is used to make up blends such as MTBE (see section II-D); the split in 1985 was 110 million gallons of methanol used to make MTBE, 105 million gallons used in oxinol, 25 million in petrocoal, and 25 million used pure ("neat") and miscellaneous. <sup>69/</sup>

Again, these projections are speculative and actual sales will depend on the results of political and governmental decisions. The methanol legislation pending in the Congress could boost the use of methanol for fuel by providing various incentives that would help to overcome what has become known as the "chicken-and-egg" problem. This is the situation in which automobile manufacturers do not wish to invest in methanol-compatible engines, since there is little methanol available to motorists; but potential methanol suppliers are reluctant to begin distributing methanol fuel, since few cars

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<sup>68/</sup> World Sugar Prices Said Forcing CBI Nations to Eye Ethanol. Alcohol Week. Nov. 23, 1985. p. 5.

<sup>69/</sup> Information Resources, Inc., Press release. Nov. 21, 1985.

can run on it. <sup>70/</sup> This problem did not exist with ethanol, since the 10 percent gasohol blend is totally compatible with existing automobile engines. Methanol in concentrations of up to 5 percent is similarly believed to be harmless to automobile engines, but methanol advocates would prefer to be able to use methanol in higher concentrations, such as the blend of 85 percent methanol to 15 percent gasoline previously discussed.

Another issue of importance to the methanol outlook concerns the "Du Pont waiver". Section 211(f) of the Clean Air Act, enacted in 1977, prohibits the use of fuels or fuel additives which are not similar to the fuels used in the certification of motor vehicles under EPA's emissions control program. The prohibition may be waived by EPA upon finding that the new fuel will not worsen atmospheric pollution. The gasohol blend has been so waived by EPA, in December 1978.

In January 1985, the EPA approved the "Du Pont waiver" for a blend containing up to 5 percent methanol, blended with at least 2.5 percent ethanol or other "cosolvent," and with a corrosion inhibitor. The Du Pont blend is intended to combine the better automotive compatibility of ethanol with the lower price of methanol in order to produce a blend which would be usable in existing auto engines at a low price. Some industry spokesmen believe that the Du Pont blend could be marketed in the large industrial States on the East and West Coasts, where the lack of the State tax exemptions prevalent in the midwestern States have prevented the gasohol blend from being economically competitive. <sup>71/</sup>

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<sup>70/</sup> U.S. Congress. House. Committee on Energy and Commerce. Subcommittee on Fossil and Synthetic Fuels. Methanol as an Automotive Fuel. Feb. 1984. p. 22.

<sup>71/</sup> EPA DuPont Decision Seen Putting Ethanol in States Without Tax Breaks. Alcohol Week (special issue). Jan. 15, 1985.

However, the EPA ruling included restrictions on allowable vapor pressure which have virtually banned this blend from the market. <sup>72/</sup>

In the long run, methanol may well be the preferred alternative to gasoline as an automotive fuel, not in a gasoline blend but used alone. Methanol from natural gas now, and eventually methanol from coal and biomass, has probable advantages over agriculturally derived ethanol as to price and supply. <sup>73/</sup> As a "neat" fuel, it could replace far more gasoline than is possible in a blend, and thus could make a major contribution to U.S. energy independence. The use of "neat" methanol would depend on having automobiles available which could operate on methanol alone. The pending legislation, which is intended to break out of the "chicken and egg" dilemma by encouraging methanol-fueled automobiles by a variety of means, is probably necessary if neat methanol is to succeed as an auto fuel. Even with enactment of this legislation, the introduction of methanol-fueled automobiles would probably be a slow process. In the interim, the increasing use of methanol blends, which might be accelerated by the need for octane boosting created by the lead phasedown could help to overcome public suspicion of methanol as an auto fuel, thus paving the way for the neat methanol vehicles to come.

#### 4. Alcohol Fuels as Octane Boosters-Some Quantitative Considerations

Some elementary calculations are instructive for calculating the potential market for alcohol fuels, should they prove economic as an octane booster.

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<sup>72/</sup> OFA Asks Court to Stay Evaporative Index Until Suit Against EPA is Settled. Alcohol Week. Dec. 16, 1985. p. 1.

<sup>73/</sup> U.S. Congress. House. Committee on Energy and Commerce. Subcommittee on Fossil and Synthetic Fuels. Methanol as an Automotive Fuel. Feb. 1984. Washington, U.S. Govt. Print. Off. (Committee Print 98-5)

a. Quantity of Alcohol Needed for Sufficient Octane Boosting to Replace the Lead Being Phased Down

In 1985, approximately 37.2 billion gallons of leaded gasoline were consumed in the United States. If the lead content of this amount of gasoline were reduced from 1.1 grams per gallon to 0.1 grams per gallon, the quantity of alcohol needed to make up the difference can be calculated. The amount of octane enhancement from TEL depends on the amount of lead added. To gain an octane value of 89 using 1.1 grams of lead per gallon, an unleaded gasoline pool of only 83.6 octane is required. Using 0.1 grams of lead per gallon requires an unleaded pool of 88.2 octane. The difference of 4.6 octane numbers is the octane value that would have to be replaced as a result of the reduction in the amount of lead in gasoline. If that difference were to be made up entirely from alcohol, the amount required can be calculated as follows:

$$P2(L) = P1 (L - A) + V(A)$$

Where:

- P2 = BOV of clear unleaded pool required at 0.1g/gal lead (88.2)
- P1 = BOV of clear unleaded pool required at 1.1g/gal lead (83.6)
- L = Amount of leaded gasoline needed to meet demand in 1985 (37.2 billion gallons)
- V = BOV of alcohol (119 for ethanol, 120 for methanol)
- A = Amount of alcohol required to equal the difference in octane enhancement of TEL from P1 to P2

Substituting numerical values and solving for A yields 4.8 billion gallons of ethanol or 4.7 billion gallons of methanol. This could be considered the amount of alcohol needed per year to replace TEL in leaded gasoline at the 1985 rate of consumption of leaded regular. This alcohol need not be added only to the leaded gasoline; it would be equally as effective for octane boosting to add some of it to the unleaded pool, thus diverting other octane

boosting capacity to the leaded gasoline. Thus the total gasoline pool could be considered a candidate for octane enhancement from alcohol.

b. Alcohol Purchase Price, Gasoline Production Price, and Alcohol Tax Advantage

The relationship between the price of alcohol, the cost of gasoline and the alcohol tax advantage can be shown by the following calculation:

Let A be the wholesale purchase price of alcohol, and let G be the production cost of gasoline. (These variables are chosen in order to illustrate how alcohol fuel use appears to a petroleum refiner, who is producing gasoline but must purchase alcohol.)

A gallon of alcohol-gasoline blend is exempted from 60 cents worth of the Federal tax, provided that there is at least 10 percent alcohol in the blend. Therefore,

$$\frac{A + 9G - .60}{10} = \text{cost per gallon} = \frac{A + xG}{x+1}$$

where the left side of the equation is the cost per gallon of a 10 percent blend of alcohol in gasoline with a 60 cent per gallon credit, and the right side is the cost per gallon of a blend with less alcohol, which would not qualify for the tax credit; and (x) is the ratio of gasoline to alcohol which would cost the same to produce without the tax credit as the 10 percent blend would cost with the credit.

Solving the above equation,

$$x = \frac{9A - 9G + .6}{A - G - .6}$$

Example 1: In early January 1986, the spot price of gasoline at New York was \$29.19 dollars per barrel, or 69.5 cents per gallon. 74/ (The production cost would be slightly less than this.) The cost of alcohol in early January was \$1.61 per gallon, f.o.b. Decatur, Illinois. 75/

Therefore  $A=1.61$ ,  $G=0.695$

$$x = \frac{14.5 - 6.3 + 0.6}{1.61 - 0.695 - 0.6} = \frac{8.8}{0.315} = 27.9$$

and  $\frac{1}{27.9} = 3.6$  percent.

This means that the cost advantage for using the 10 percent blend is retained with decreasing amounts of alcohol until a 3.6 percent blend is reached. A refiner would not minimize costs with an alcohol concentration of between 3.6 percent and 10 percent, in this example, because it would be less expensive to use 10 percent alcohol and take advantage of the tax exemption. Below 3.6 percent the cost difference between alcohol and gasoline becomes controlling, and use of the lower concentration would become economically justified.

Example 2: In early March 1986, the spot price of gasoline had reached \$19.02 per barrel, or 45 cents per gallon. 76/ The cost of alcohol by early March had reached \$1.23 per gallon. 77/

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74/ Weekly Petroleum Status Report. Energy Information Administration. Mar. 14, 1986.

75/ Alcohol Outlook, Jan. 1986.

76/ Weekly Petroleum Status Report. Energy Information Administration. Mar. 14, 1986.

77/ Alcohol Outlook, Mar. 1986.

So  $A=1.23$ ,  $G=0.45$

$$x = \frac{11.1 - 4.1 + 0.6}{1.23 - 0.45 - .6} = \frac{7.6}{0.13} = 58.5$$

and  $\frac{1}{58.5} = 1.7$  percent.

Perhaps surprisingly, the two calculations show that between January and March 1986, the "break-even point" for alcohol-gasoline blends was dropping in terms of percent of alcohol in the blend. This is because, while the price of gasoline was dropping sharply during this period, the price of alcohol was dropping even more sharply, thus alcohol was becoming more competitive with gasoline. Once the price of alcohol closed to within 60 cents of the price of gasoline, it would always be less costly to use 10 percent blends instead of lower concentrations of ethanol. A continuing decrease in gasoline prices presumably would soon reverse this trend, as alcohol producers would become unable to match this decline and continue to make a profit.

c. Maximum Possible Amount of Alcohol Which Refiners Could Use in Connection with Lead Phasedown

From the calculation in section a, it can be seen that if one assumes that the entire pool of previously leaded gasoline were to be "octane-boosted" by using alcohol, the amount of alcohol required to do the requisite octane boosting would be 4.8 billion gallons of ethanol, or 4.7 billion gallons of methanol. Within the 100 billion gallon gasoline pool, this would mean using a concentration of alcohol of slightly under five percent. However, section (b) shows that, assuming the excise tax exemption stays as it is in current law, a refiner would be unlikely to use a five percent blend, which would not qualify for the tax exemption, when he could go to a ten percent blend and get

the exemption. (Staying at five percent would only be preferable if the price of gasoline became very low or the price of alcohol very high, and those conditions would probably preclude the use of alcohol altogether.)

Thus the amount of alcohol fuel that might be required to totally replace the lead being phased down can be calculated by assuming a ten percent blend would be used. Given a 100 billion gallon pool of gasoline, 10 billion gallons of alcohol fuel would be required.

In reality, because of the various factors that each individual refiner must take into consideration, it would be highly unlikely that every refiner in the U.S. automotive fuels market would choose to use alcohol fuel (or indeed any other possibility) as a replacement of lead. These calculations are useful in that they define a maximum possible alcohol fuels market resulting from the lead phasedown. The actual market opportunity for alcohol fuels would be significantly less than this for three reasons. The main reason is that many refineries have already embarked on processing options to increase octane. Further, the consumption of leaded gasoline is expected to decline in the near future, and although unleaded gasoline consumption is expected to increase, unleaded regular has a lower octane rating (87). Finally, as more fuel-efficient cars replace older vehicles, gasoline consumption is expected to drop off until increasing numbers of vehicles bring it back up. This may provide market opportunity for alcohols in the longer term, but less than that calculated above for the near term.

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## IV. CONCLUSIONS

Replacing the octane enhancement of lead in gasoline being removed by the lead phasedown represents a total market opportunity of roughly ten billion gallons per year for alcohol fuel. This is far in excess of the present level of under a billion gallons per year of alcohol fuels used in the United States. However, a significant portion of this market is unlikely to be captured if the alcohol fuels industry continues to be involved in intramural fights between domestic ethanol producers, ethanol importers, and methanol producers.

The petroleum refiners have a choice of options for replacing lead as a gasoline octane booster. In choosing their course of action, refiners must consider many variables, and the optimum path will vary from one refiner to another. But almost certainly, one of the factors each refiner will consider is stability and continuity of supply. If the refiners do not believe that alcohol fuels offer them that stability, they are likely to choose other octane boosting options.

In the present situation, alcohol fuels can be obtained from three major sources: domestic ethanol, imported ethanol, and methanol. Most of the demand for alcohol fuels is now met by the domestic ethanol producers. These producers have strongly opposed ethanol imports from Brazil and the CBI nations, through actions filed with the international trade agencies and through their ability to lobby the Congress. While these efforts may well be successful, the domestic

producers should consider that their victory might be a hollow one if, by keeping out the imports, they lose the chance to pick up a major portion of the potential market opened to them by the lead phasedown.

Most of the domestic fuel alcohol production uses Midwestern corn as the feedstock. As farmers well know, any agricultural crop faces numerous uncertainties which affect its successful production and marketing. Weather-related problems can cause shortfalls in anticipated crop yields, and famines or wars in other nations can cause increases in demand which lead to supply shortages and possibly to price increases. A petroleum refiner, facing the question of how to replace the lead phased out of his refinery's gasoline, will have to consider these uncertainties as he contemplates the use of alcohol fuels as octane boosters. He may be more likely to choose alcohol if a shortfall in the corn crop can be made up by alternative alcohol supplies, such as imported Brazilian ethanol or DuPont-blend methanol.

With regard to methanol, its difficulties in becoming established as a major component in the alcohol fuels market do not appear to stem from ethanol producer opposition. The problem here is that methanol by itself is less compatible with existing automobile engines than is ethanol. The DuPont blend of 5 percent methanol and 2.5 percent ethanol with gasoline would be usable in existing automobiles, but use of this blend has been stymied by the EPA's vapor pressure restrictions. Easing of these restrictions on the DuPont blend would be most helpful to the alcohol fuels industry, as these blends could combine the price advantage of methanol with the automotive compatibility of ethanol, thus making them marketable in the States which do not have their own "tax breaks" for alcohol fuels.

Each of the three major sources of alcohol for fuel, domestic ethanol, imported ethanol, and methanol appears to have an advantage over the others

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in a particular region of the country, and each has the potential for becoming the major alcohol fuel supplier to that region. Domestic ethanol could continue to dominate the market in the Midwestern States, where it is already well established. Imported ethanol from Brazil and the CBI nations could be marketed in the major Sun Belt States, such as Florida, Texas, and California, which are further from domestic producers and near suitable ports for imports. Methanol, probably mixed with some ethanol in the Du Pont blend, could be used in the Northeastern Industrial States, which are distant from Midwestern corn and from the countries south of the United States, and for this and other reasons have thus far resisted market penetration by ethanol blends. Thus the present and potential structure of the United States alcohol fuels market could lend itself to a regional approach which could minimize conflict among the suppliers.

The recent sharp drop in petroleum prices has caused difficulties for all segments of the alcohol fuels industry. Alcohol now is competing directly with gasoline for a share of the automotive fuels pool, thus it necessarily suffers when the price of gasoline is lowered. Alcohol fuel advocates believe that once alcohol is accepted as an octane enhancer and not simply as a gasoline extender, it will no longer be in direct price competition with gasoline; instead, it will be priced in competition with other octane boosting methods, and therefore will be less vulnerable to fluctuations in gasoline prices. It should be noted as well that the low oil prices of late 1985 and early 1986 may be a short-term phenomenon. Some experts on oil prices believe that their recent rapid fall may soon be followed by an equally rapid rise. If this proves true, the difficulties caused in the alcohol fuel industry by low oil prices may be similarly short-lived.

In summary, the lead phasedown may provide an opportunity for the alcohol fuels to be the replacement octane booster preferred by many of the oil refiners, and therefore to increase their sales far above existing levels, provided that this new industry can take advantage of the opportunities before it.

